Eastern Research Group, Inc.

Evaluation of the Texas Inspection and Maintenance Program in the Austin Area

Prepared for:

Texas Commission on Environmental Quality

Prepared by:

Eastern Research Group, Inc.

January 22, 2015

ERG No.: 0292.01.013

Evaluation of the Texas Inspection and Maintenance Program in the Austin Area

Prepared for:

Edgar Gilmore
Texas Commission on Environmental Quality
12100 Park 35 Circle
Austin, TX 78753

Prepared by:

Cindy Palacios
Scott Fincher
Jim Lindner

Eastern Research Group, Inc.
3508 Far West Blvd., Suite 210
Austin, TX 78731

January 22, 2015

Table of Contents

List of Tables

List of Figures

Executive Summary

This report documents the evaluation of the Texas Inspection and Maintenance (I/M) program in the Austin area for the 2012 and 2013 biennial period. Eastern Research Group (ERG) performed this evaluation for the Texas Commission on Environmental Quality (TCEQ) using the Texas Information Management System (TIMS) database data and Remote Sensing (RS) data from January 1, 2012 through December 31, 2013.

This evaluation generally follows the United States Environmental Protection Agency (EPA) draft guidance on using in-program data for the evaluation of the I/M program performance [Reference 1][1] and the EPA guidance on the use of RS for the evaluation of I/M program performance [Reference 2]. This study is focused on program coverage, the inspection process and the repair process. Additionally, program benefits were estimated on an annual basis. It also very closely follows the format used in the most recent 2014 evaluation of the Dallas-Fort Worth (DFW) and Houston-Galveston Brazoria (HGB) programs [Reference 3]. Some statistics between the Austin and DFW/HGB programs are compared; however, these must be taken in context because the fleet size is much smaller in Austin than the DFW/HGB programs.

Overall, the results for the Texas Austin I/M program were positive; however, in the course of performing this evaluation a few areas were found where improvements could be made. Additionally, some of these suggestions will be helpful for future biennial evaluations and make the results more reflective of program performance. The last section of this Executive Summary provides a list of specific recommendations where ERG feels improvements in the program could be made.

Coverage

The results of the coverage analysis using out-of-program data revealed a consistent, high rate of participation in the I/M program.

Participation Rates (Section 2.1) – The program participation rates were estimated by determining the fraction of vehicles seen on the road during RS studies that had recent records in the TIMS. If an I/M test occurred any time between January 2012, and December 2013, and was found to link up with a RS measurement taken any time between January 2012 and December 2013, this was a matched pair. Using this method of analysis it was estimated that the compliance rate was 86.2% which is essentially identical to the 86% observed in the DFW/HGB areas in the most recent 2014 evaluation report [Reference 3].

[1] Citations for references are given in Section 7.

Inspection

Appropriateness of Major TIMS Fields (Section 3.1) – The TIMS is used to document the I/M program inspection process. The analysis in this activity checked the major fields in the TIMS using a series of basic data checks to demonstrate the accuracy and completeness of the data in the TIMS. ERG produced frequency distributions of almost all database variables to examine field values for in-range values, out-of-range values, and missing values. The following summarizes the major findings of this analysis:

- Frequency distributions of Two-Speed Idle (TSI) hydrocarbon (HC) and carbon monoxide (CO) were typical for vehicle emissions data, as the distributions are all positively skewed (that is, most observations are at low emissions concentrations), and there is no evidence of large numbers of very high concentration values. The shapes of the distributions look typical for a fleet of modern in-use vehicles. Overall, the figures indicate that no gross errors are being made in measuring and recording tailpipe emissions. Very few out-of-range emission values were found.

- The analysis of the TIMS data indicated that approximately 0.14% of the TSI CO_2 measurements had concentrations greater than the theoretical limit of 16%, with 0.23/0.43% (curb idle/fast idle) below 6%. These values the DFW/HGB 2014 report were 0.83% and 0.63/0.37%, respectively.

- The analysis of the validity of vehicle identification numbers (VIN) in the TIMS indicated that roughly 0.016% of the VINs had either illegal check digits or a check digit that did not agree with the check digit calculation. This value is lower than that seen in the 2014 DFW/HGB report (0.105%).

Inspection Statistics (Section 3.2) – Analysis of the TIMS data indicated that during the evaluation period over 1.8 million TSI and On-board Diagnostic (OBD) tests were performed on over 1.1 million vehicles. During the same timeframe in the DFW and HGB programs there were 14.7 million ASM, TSI, and OBD tests performed on more than 13.9 million vehicles. Approximately 95% of the tests were OBD and 5% were TSI in Austin, while for the DFW and HGB programs 94% of the tests were OBD, 5% were ASM and 5% were TSI.

Repeat I/M Failure Patterns (Section 3.3) – ERG examined the TIMS data to determine the relative frequencies of the I/M pass/fail patterns during each vehicle's inspection cycle.

- Approximately 99.3% of the test sequences were found to be made up of a verified initial test, or an initial test that could reasonably be assumed to be a true initial test, and a final test that was certified. This number was 99.7% in the 2014 DFW/HGB report.

Emissions Analyzer Data Quality (Section 3.4) – The TIMS data were analyzed to determine the quality of the emissions measurements made by the emissions analyzers. Specific analyses were made using instrument calibrations to check for drift, individual inspection results checking for the stoichiometrically correct measured concentrations of CO, CO_2, and oxygen (O_2), gas audit results to validate analyzer accuracy, and comparison of instrument calibrations with inspection results to check for proper lock-out of emissions equipment. The following provides a summary of the results:

- The drift of the emissions analyzers was measured by comparing the pre-calibration measurements of calibration gas with the post-calibration values. With the exception of the zero gas for HC, the analysis showed that more than 86% of the pre-calibrations fell within the tolerance of the analyzer after the analyzer had been given an opportunity to drift for 72 hours between calibrations. This indicates that results for more than 90% of the I/M inspections performed just before the calibration can be expected to be within the instrument tolerance except for very low values of HC. This value was 85% in the 2014 DFW/HGB report.

- More than 99.9% of calibration records included bottle gas label concentrations that were within the prescribed tolerances. However, the remaining small fraction of records did include some (73 records) surprisingly high and low bottle gas values. It is possible that the bottle gas concentration was entered incorrectly into the TIMS or that the outlying values represent real bottle gas mixtures that were occasionally used. In the DFW/HGB program there were 7 records of this type.

- The Texas state implementation plan (SIP) requires that each analyzer be audited at least twice per year. The TIMS data indicates that over 92% of the analyzers in the state were audited at least twice per year and many of them were audited many more times than that. During the same time period, over 95% of the analyzers in the DFW/HGB program were audited twice or more.

- Calibration records, analyzer gas audit records, and vehicle inspection records were used to determine whether analyzer calibrations were taking place as required, and whether uncalibrated analyzers and dynamometers were locked out until passing a calibration. Comparison of TSI test records with analyzer gas calibration and leak check records appear to indicate that for the majority of analyzers, 72-hour lockouts are independently enforced for each of these three calibrations/checks (i.e., the analyzer system must pass all three tests every 72 hours or it will be locked out). Similarly, 0.51% of TSI inspections were performed when the analyzer should have been locked out. The lock out values were 0.3% in the 2014 DFW/HGB report.

OBD Inspection Analyzer Communication Performance (Section 3.5) – Overall OBD communication rates between vehicle's computers and program analyzers was greater than 99.9%. This mirrors the very high communication performance seen in the DFW and HGB programs.

TIMS Handling of OBD Codes (Section 3.6) – As in the DFW and HGB programs, it appears that the OBD inspection logic used in the Austin program for light-duty gasoline-powered vehicles is in agreement with the EPA policies. For the very few cases where this was found not to be true, ERG believes these instances are due solely to a minor oversight such as operator error or analyzers not having the latest software update for a brief period that resulted in a small percentage of errors.

Repair

Number and Types of Repairs (Section 4.1) –Analysis of the TIMS data indicates that over 28,932 I/M program induced repairs were made to vehicles during the evaluation period. For DFW and HGB, this figure is much larger (230,138) as it reflects the difference in fleet size. The I/M program requires reporting the types of repairs in five categories: fuel system, ignition electrical system, emissions system, engine mechanical, and miscellaneous. The fractions of total repairs in these five categories were approximately 21%, 4%, 25%, 1%, and 49%. For the DFW/HGB programs these values were 20%, 9%, 29%, 2%, and 40%, respectively.

The Department of Public Safety (DPS) collects separate repair information from stations that volunteer to be designated Recognized Emission Repair Facilities (RERF). The repairs reported from RERF stations have much more detailed descriptions than the five categories used in the TIMS. However, the RERF program is voluntary and only about 252 repairs were reported to DPS. This figure was 3,710 for the DFW/HGB programs.

A third source of repair information is the Drive a Clean Machine (DACM) program. Texas created the DACM program under the statutory authority granted in the Low Income and Repair Assistance, Retrofit, and Accelerated Vehicle Retirement Program legislation. This program provides assistance to low income individuals by repairing or retiring vehicles that have failed an emissions test. DACM numbers are reported quarterly so the evaluation period for the RERF numbers are from the dates 12/1/2011 through 11/30/2013. During the same time period there were 252 total DACM repairs made with 8,098 made in DFW and HGB under the DACM program.

Emissions Changes Associated with Repairs (Section 4.2) – ERG analyzed the Texas TIMS data obtained during the evaluation period to determine the change in emissions of repaired vehicles before and after repair. The apparent emissions concentration changes for TSI HC and CO were both approximately 72%. The DFW and HGB program values are based on ASM test results and showed HC/CO/NOx decreases of approximately 67%, 81%, and 70%, respectively.

OBD Repair Effectiveness (Section 4.3 and 4.4) – ERG's analyses indicates approximately 71% of OBD tests that initially receive a fail for illuminated malfunction indicator light (MIL) with stored diagnostic trouble codes (DTCs) eventually receive a certificate. This value is lower than the 85% seen in the DFW/HGB programs. It was also observed that the Austin repair rates were lower than those seen in the DFW/HGB programs, and Austin also has a greater percentage of disappearing vehicles.

Average Repair Costs (Section 4.5) – The analysis of the TIMS repair cost data with repair costs of zero and greater than $2,000 removed indicate that Texas motorists spent at least $1.9 million during this evaluation period performing 10,648 repairs so that they would be in compliance with the I/M programs, but it should be noted that TIMS inspectors hand-enter repair costs and, accordingly, these values can have errors. The amount spent on repairs for the DFW/HGB programs during this time was approximately $22.4 million on some 216,893 repairs.

As observed in previous DFW/HGB studies, a large percentage (60.5%) of the repair costs in the Texas TIMS was recorded as zero. In the DFW/HGB programs this value was 50%. Again, with zero repair costs and those over $2,000 removed, the median and mean repair costs ranged from $40-$250 and $76-371, which is comparable to the $40-$235 and $92-$296 seen in the 2014 DFW/HGB report.

The mean repair costs for repairs performed by the RERFs were significantly higher ($400-$650) than those seen in the TIMS data ($150-$200); however, this discrepancy is also seen in the DFW/HGB analysis. ERG does not believe the difference in repair costs between all repair stations and the RERF stations are inconsistent. It is expected that the repair costs for RERF stations will be higher than average repair stations since these stations voluntarily participate in the RERF program and, therefore, are more likely to make repairs that are more technically challenging and, therefore, more expensive.

I/M Emissions Benefits

The Annual I/M Benefit of an I/M program can be measured by the decrease in emissions for the I/M fleet at the time of vehicle repairs. The Annual I/M Benefit was estimated by looking at before and after repair emissions and also by pairing TIMS data with RS data.

Estimate of Annual I/M Benefits from TIMS Data (Section 5.1) – Using the initial and final emissions concentrations of annual inspection sequences as recorded in TIMS data, which is in-program data, we calculated the change in emissions concentrations at the time of inspection. About 95.2% of the I/M sequences were produced by vehicles that simply initially pass. Additionally, about 4.1% of the TSI I/M sequences were produced by vehicles that initially failed, were repaired, and finally passed. Again, these rates are very similar to those seen in the DFW/HGB report, 94.6% and 4.6% respectively.

These sequences were associated with emissions reductions at the I/M inspection of 18-23%. These concentrations for the TSI inspection are similar to those that were seen for TSI inspections in the DFW/HGB program areas.

Estimate of Annual I/M Benefits from Paired I/M and RS Data (Section 5.2) – The analysis of RS data, which is out-of-program data, provides a different view of the Annual I/M Benefit of the I/M program. The average RS emissions from 30 to 90 days before I/M inspections were compared to the average RS emissions from 1 to 90 days after the I/M inspections. About 95.7% of the vehicles measured by RS had I/M sequences produced by passing their initial inspections, while 3.9% had a Fail-Pass I/M test sequence. This is essentially identical to the values seen in the DFW/HGB 2014 report.

Measures for Evaluating Station Performance (Sections 6.1 and 6.2) – This section strives to consolidate the analyses performed that pertain to the evaluation of station performance. Distinctions between errors of commission vs. errors of omission were also identified whenever possible, with the former viewed as more likely attempts at committing a fraudulent test, while the latter could be viewed somewhat more leniently. An example of an error of commission would be a VIN mismatch, where the OBD-downloaded VIN does not correspond to the hand-entered VIN. In the benign case, the discrepancies are basically random. In a highly suspicious case, the exact same OBD-downloaded VIN may be found in roughly 1,000 tests, which seems to indicate a clear case of attempted clean-scanning. An example of an error of omission metric is a zero-value repair cost as this will not result in falsely passing or failing the I/M test. In all, there were 6 error of commission and 10 error of omission metrics developed and each station was ranked according to their respective overall score in these two categories.

Recommendations and Comments

As a result of performing this biennial evaluation of the Texas I/M program, ERG has developed a list of recommendations Texas should consider implementing. As in the earlier reports, the purpose of most of these recommendations is to improve the program, but some also are intended to improve future biennial I/M program evaluations. For each recommendation, ERG has provided an importance rating of High

(***), Medium **(**)**, or Low **(*)**. These ratings are provided to assist the TCEQ in prioritizing efforts to improve the I/M program.

OBD Recommendations

The future of vehicle testing at I/M inspection stations in Texas will continue to be dominated by OBD testing, as it replaces tailpipe emissions testing; therefore, any OBD problems identified in this evaluation are viewed as more critical to the overall success of the program.

Recommendation 1 (***): Investigate requiring a "set" status for certain monitors to prevent hiding malfunctions. Our analysis found that in 3% to 41% of instances when a vehicle received an initial fail for a certain monitored component, the retest OBD result, which follows a repair, could be hidden by an "unset" readiness status for that monitor. This opens up the possibility that malfunctioning emissions control components could remain unrepaired even though the follow-up OBD test received a "pass." ERG recommends the TCEQ investigate implementing a software change that would require certain monitors to have a "set" readiness status on an OBD retest that follows certain types of initial failures. Similar observations were made in the DFW/HGB 2014 report.

Recommendation 2 (***): Improve response to trigger flags. ERG believes the current trigger system is well designed and well run. However, in some programs it has been found that the trigger system can identify more issues than can be addressed with available resources. Therefore, ERG's primary recommendation is to assess the current level of response to the existing triggers, and then determine if additional triggers would be beneficial to the program. Specifically, a simple count of the number of triggers and the corresponding number of responses would be helpful to assess the current effectiveness of the triggers program. This recommendation was also made in the 2014 DFW/HGB report.

Recommendation 3 (***): Repair Effectiveness and Disappearing Vehicles. It was noted that the repair rate in the Austin program was markedly lower than that seen in the DFW/HGB programs and that the level of disappearing vehicles is also greater in the Austin area. It is recommended that additional work be performed to understand the reasons for these differences.

Recommendation 4 (*): Diesel OBD and Heavy-duty Gasoline OBD. Per the EPA guidance, Texas does not perform testing on OBD light or heavy-duty diesels or heavy-duty gasoline vehicles. However, this topic continues to be discussed in the I/M community. EPA's position on this may change in the near future or pilot testing could be performed in some jurisdiction and ERG would suggest the TCEQ stay abreast of any developments in this area.

TSI Recommendations and Comments

Even though OBD testing will eventually replace tailpipe emissions testing in Texas, tailpipe testing will probably be used on the 1995 and older vehicles for some time. Therefore, efforts need to continue to provide quality tailpipe tests and accurate TIMS records of them. Given the ever decreasing number of tailpipe tests, Texas may want to consider moving to an OBD-only program, although this would require of MOVES modeling analysis to quantify the projected loss in emission reductions.

Recommendation 1 (***): Improve response to trigger flags. The same recommendation and associated caveats for the OBD vehicles regarding triggers outlined above also apply to TSI tests.

Recommendation 2 (*): Reject calibration bottle concentration values that are outside the specified range. Our analysis of analyzer gas calibration data indicated that about 0.1% of the bottle gas label concentrations were outside of the acceptable tolerances. In this analysis there were 73 such records. In the DFW/HGB 2014 report there were 7 records like this.

RS Recommendations and Comments

In the past, initial measurements of tailpipe emissions at the annual I/M inspection could be used to track fleet emissions. However, as tailpipe emissions measurements are being replaced by OBD testing, vehicle emissions levels are no longer routinely measured and recorded. That leaves RS as the only major source of data to monitor the emissions of the fleet in the future. Because of this trend, it is important to address any RS problems seen in this evaluation as soon as possible, even if they appear to be relatively minor right now.

Recommendation 1 (**): Collect RS data in San Antonio. In the 2009 DFW/HGB Report ERG was able to use RS data from San Antonio to analyze the DFW/HGB RS fleet data using the Reference Method. If possible, efforts should continue to obtain RS data from San Antonio for future evaluations. This data could then be used for analyses of the Austin or DFW/HGB programs.

Vehicle Tracking Recommendations

Whether vehicles are inspected or measured by TSI, OBD, or RS, these sources of data on individual vehicles can be used effectively only if vehicles are identified and tracked accurately in all of the databases. A major part of the effort in this biennial evaluation was spent trying to properly identify TIMS and registration data for individual vehicles. Because transcription errors of VINs and plates were common in these databases, in the end ERG could provide only approximately correct vehicle histories that were needed for the analyses. The following two recommendations are the most important vehicle tracking recommendations resulting from this biennial evaluation.

Repair Tracking Recommendations

Whether malfunctioning vehicle emission control systems are detected by TSI or OBD, Texas should consider improving the system of recording the repairs that are made to vehicles. The repairs, not the inspections, keep vehicle emission control systems operating properly and, in turn, maintain low vehicle emissions.

Recommendation 1 (***): Use a more detailed, but short, list of repairs for I/M inspectors to choose from. The TIMS gives inspectors five general repair categories to use to report I/M-induced repairs and these categories appear too broad to be useful. It is recommended that Texas develop an improved system for reporting I/M-induced vehicle repairs that contains more detail, providing inspectors a list of the 5 to 10 most emissions-influential repairs for the technology of the vehicle that the inspector is working on. These repair types have already been determined by an analysis of British Columbia I/M program repair and ASM emissions data. Other information on the myriad of other repairs that might have been performed is not needed because they have minor influences on emissions. This approach would make a convenient, short list of repairs for inspectors that would make the inspector's task simpler, while recording the valuable repair information that is most important for the I/M program. This is also a critical element in making program evaluation projections, as without reliable repair data, be it an OBD or non-OBD vehicle, it is not possible to link emission reductions to repair.

It might be worthwhile to consider a software change that would require the inspector to input repair information within set limits of price and from a menu selection of repair choices. Providing more standardized menu options would also help improve the accuracy of this data by standardizing the entries as well as making it more onerous for the technician to enter incorrect data than actually enter the real data. If it becomes more difficult to input bogus data than the actual real data, then technicians would be motivated to be more accurate when completing these electronic entry forms.

Finally, standardizing the RERF and TIMS repair forms might help improve repair data analysis in the future.

1.0 Introduction

The EPA requires that states with I/M programs submit an evaluation of their programs every two years to their EPA Regional office. The TCEQ conducted the most recent biennial evaluation in the 2009 Report and, in consultation with ERG, has chosen a set of evaluation elements that will comprehensively, yet simply, document the performance of the Texas I/M program for the most recent two years and adhere to the program evaluation requirements outlined by the EPA.

1.1 Evaluation Analysis Approach

The Clean Air Act requires that states evaluate their I/M programs every two years. The Sierra Method was used to evaluate the previous version of the Texas I/M program in 2000 [Reference 7] and later ERG used the updated EPA guidance [References 1 and 2] as a framework for an evaluation performed in 2006 [Reference 4]. Since then, ERG has performed evaluations in 2009 [Reference 5] and 2012 [Reference 6] using the same approach as the 2006 Report.

This report on the Austin program follows the same general approach, as it focuses on analyzing and evaluating data to assess program coverage, the vehicle inspection process, the vehicle repair process, program air quality benefits, and station performance. These areas were chosen to provide the most useful information at reasonable cost, as well as provide an objective assessment on the overall status of the I/M program, with the intent of identifying both areas that may be improved upon and those that are performing well.

1.2 Structure of the Report

As previously stated, this report follows the same outline as the previous DFW/HGB reports. Section 2 investigates coverage first by examining the results of a recent parking lot survey of windshield registration stickers and by comparing vehicle license plates read during RS measurements with the vehicles seen in the I/M program TIMS database.

Section 3 investigates the inspection process in various ways using the TIMS data for the evaluation period. For example, TIMS data fields were checked for appropriate ranges, the various types of inspections and failure patterns were counted, the emissions analyzer calibration and audit results were checked, and OBD communication rates and test outcomes were examined.

In Section 4, the TIMS data and Recognized Emission Repair Facility (RERF) data were analyzed to determine the level, cost, and emissions and OBD effects of repairs associated with the I/M program.

Section 5 provides emission benefits estimates based on TIMS and RS data. Some of the analyses done in this section were not part of the original work plan, but were performed at no additional cost.

Section 6 is a fairly detailed analysis of station performance based on TIMS data. It covers errors clear errors of commission, such as “clean-piping” or VIN mismatches, as well as errors that are more difficult to categorize such as data entry issues or anomalous test results.

2.0 Coverage

An important component of an I/M program is the level of fleet coverage, or the vehicle compliance rate. In this section, coverage is evaluated by estimating the fraction of vehicles observed on the road using RS data that also have a current and valid I/M program TIMS record.

2.1 Participation Rates

Estimates of the participation rate of vehicles subject to I/M in the Austin area were made through a comparison of RS data and TIMS data. RS data provides a sample of vehicles that were driven on the road. If these vehicles were eligible for I/M, they should have been participating in the I/M program. TIMS and RS data were analyzed to determine the I/M compliance rate of on-road vehicles during the period of evaluation.

ERG first created a dataset of I/M-eligible and I/M-county registered vehicles captured on the road with RS at least once. This dataset does not include vehicles from out-of-state or registered in non-I/M counties. This dataset only consists of I/M-eligible model years. That is, vehicles newer than 2 years and older than 24 years at the time of the RS measurement are excluded from the analysis. Table 2-1 shows the counts of unique I/M-eligible vehicles from the Austin program areas which were measured by RS between January 2012 and December 2013.

Table 2-1. Count of Unique I/M-Eligible Remote Sensing Vehicles Registered in I/M Program Areas

Registered at Time of Remote Sensing	Unique RS-Captured Vehicles
AUS	55,435

Next, the number of unique I/M-compliant vehicles (vehicles that were tested and ultimately passed or received a waiver) in each of the I/M Program Areas was determined. Table 2-2 shows the counts for the Austin program area.

Table 2-2. Count of Unique I/M-Compliant Vehicles in I/M Program Areas

I/M Area where Test Performed	Unique I/M-Tested Vehicles
AUS	1,125,429

The I/M tests were then matched to RS measurements by GroupID, which is our best estimate of the correct VIN. If an I/M test occurred any time between January 2012, and December 2013, and was found to link up with a RS measurement taken any time between January 2012 and December 2013, this was a matched pair. Of the 55,435 RS measurements in Austin, there were 47,768 pairs of matched I/M-test and RS measurements for an 86.17% participation rate. While these percentages are our best estimate of I/M compliance, it is worth noting that some of the non-matches may be attributable to RSD OCR license plate errors, mismatches and/or typos on plates in registration data, and/or VIN/plate mismatches from TIMS I/M data.

A further refinement to the participation rate was to look at a distribution of time differences between the matched pairs of RS to certifying I/M tests. For this evaluation, I/M tests both before and after RS measurement events were considered. If no I/M test was performed within 15 months from the time an on-road RSD measurement was collected, then one may assume that vehicle is no longer participating in the I/M program. However, if the time difference is between 12-15 months, these vehicles may actually be participating in the I/M program - the motorist likely was late for the I/M test or the delay was a result of vehicle repairs (since the final test can occur a few months after the initial I/M test). Table 2-3 shows the distribution of time differences between matching pairs in each I/M program area. It should be noted that the 2.5% of vehicles in the Austin area may be attributed not only to non-compliance but also to vehicles becoming ineligible for the I/M program (vehicle becomes too old, leaves the program area, or is taken off the road). These figures do not include any vehicles retired by the DACM program.

Table 2-3. Time Between Remote Sensing and I/M Test

I/M Program Area	Time Difference Between RS and I/M Test	Count	Percent
AUS	<12 months	48,465	95.4
	12 -15 months	1,072	2.1
	> 15 months	1,276	2.5
	Total	50,993	100.0

3.0 Inspection

3.1 Check Major TIMS Fields for Appropriateness

The goal of this check was to analyze the ranges and values of the primary variables that make up the TIMS database. This analysis is an indication of the ability of the I/M program's analyzers and TIMS database system to accurately record the activities of the I/M program. If TIMS variables have values that are out of range or missing for unexplained reasons it suggests that the I/M program activities are not being conducted properly or adequately monitored.

Since in-program data is the primary basis of the I/M program evaluation, a series of steps were used to evaluate the accuracy and completeness of the data in the database.

1. All records which were created outside the period of evaluation were eliminated. The beginning and ending dates of the data under consideration include:
   - I/M Test Records: January 2012 – December 2013.
   - Remote Sensing Measurements: January 2012 – December 2013.
2. A frequency distribution was performed of nearly all database variables to evaluate the accuracy and completeness of data fields. These frequency distributions included only filtered data[2], so many missing values and unreasonable values were removed during the filtering process. Throughout this report, additional details about the accuracy and completeness of individual fields are noted.

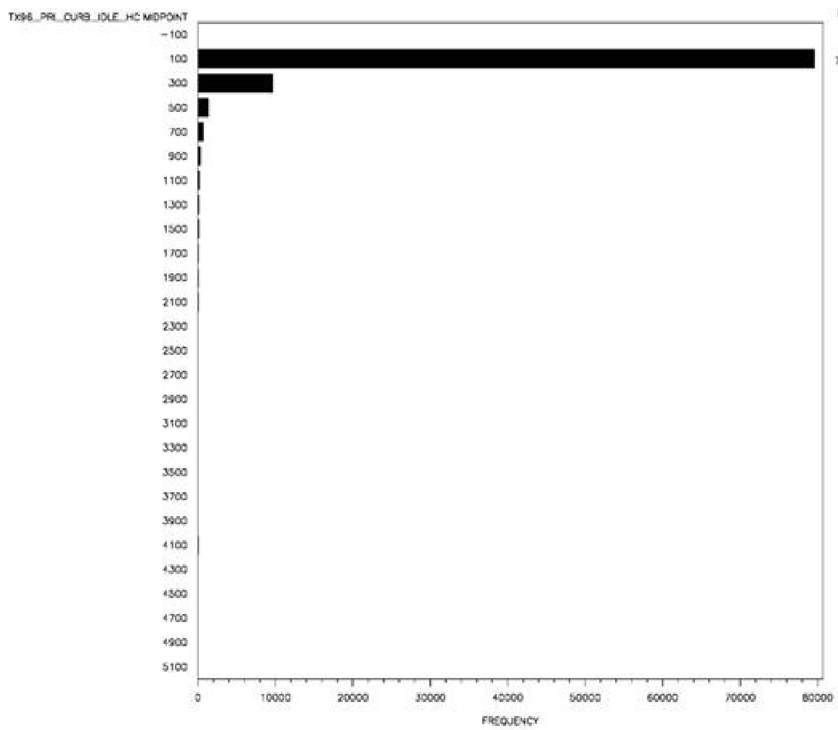
The following is a list of some findings after checking the various TIMS fields:

- Duration of tailpipe test times is missing on 32.9% of the TSI tests. In addition, 0.53% of TSI tests had invalid negative test times.
- RPM bypass is used on 4.58% of the TSI tests.
- A distribution of the emissions measurements is a special case of the above. Ideally, no observations with missing values should be present. Figures 3-1 through 3-4 show the distributions of the emissions measurements for HC and CO for TSI tests in the Austin program area. The distributions are all positively skewed (that is, most observations are at low emissions concentrations), and there is no evidence of large numbers of very high concentration values. The shapes of the distributions

[2] These filters included things such as keeping only HGB and DFW records, and flagging items such as aborted tests, covert vehicles, safety-only tests, vehicles with blank Pass/Fail results, etc.

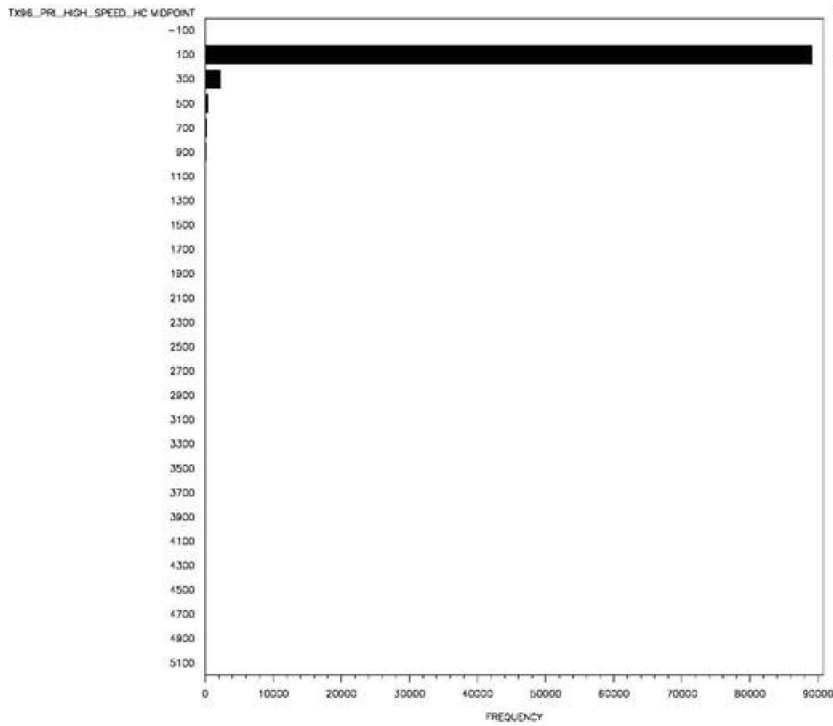
look typical for a fleet of modern in-use vehicles. Overall, the figures indicate that no gross errors are being made in measuring and recording tailpipe emissions. Also, all observations should have a CO_2 concentration between about 6% and 16%, since a combustion process must be present. Table 3-1 shows the distribution of CO_2 measurements.

Figure 3-1. Distribution of TSI HC Curb Idle Concentrations for All Filtered I/M Tests



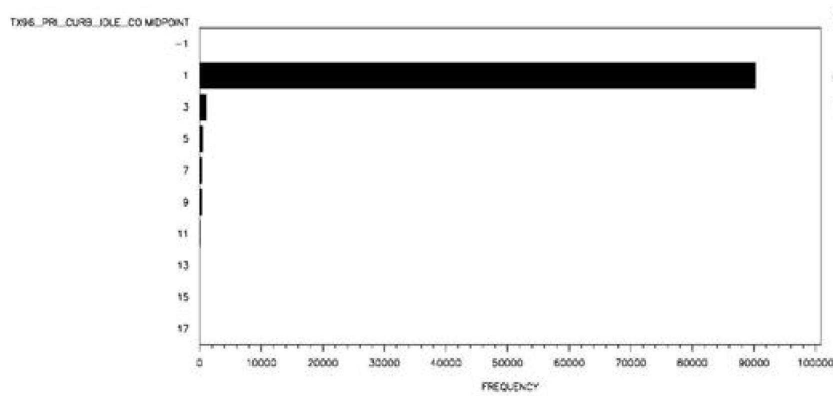
TX96_PRI_CURB_IDLE_HC MIDPOINT	FREQ.	CUM. FREQ.	PCT.	CUM. PCT.
−100	0	0	0.00	0.00
100	79575	79575	86.12	86.12
300	9621	89196	10.41	96.53
500	1398	90594	1.51	98.06
700	626	91220	0.68	98.72
900	345	91565	0.37	99.10
1100	172	91737	0.19	99.28
1300	139	91876	0.15	99.43
1500	90	91966	0.10	99.53
1700	75	92041	0.08	99.61
1900	63	92104	0.07	99.68
2100	43	92147	0.05	99.73
2300	26	92173	0.03	99.76
2500	33	92206	0.04	99.79
2700	23	92229	0.02	99.82
2900	21	92250	0.02	99.84
3100	17	92267	0.02	99.86
3300	13	92280	0.01	99.87
3500	17	92297	0.02	99.89
3700	10	92307	0.01	99.90
3900	15	92322	0.02	99.92
4100	58	92380	0.06	99.98
4300	2	92382	0.00	99.98
4500	2	92384	0.00	99.98
4700	0	92384	0.00	99.98
4900	0	92384	0.00	99.98
5100	15	92399	0.02	100.00

Figure 3-2. Distribution of TSI HC High Speed Concentrations for All Filtered I/M Tests



TX96_PRI_HIGH_SPEED_HC MIDPOINT	FREQ.	CUM. FREQ.	PCT.	CUM. PCT.
-100	0	0	0.00	0.00
100	89015	89015	96.34	96.34
300	2156	91171	2.33	98.67
500	424	91595	0.46	99.13
700	208	91803	0.23	99.35
900	127	91930	0.14	99.49
1100	79	92009	0.09	99.58
1300	57	92066	0.06	99.64
1500	42	92108	0.05	99.69
1700	38	92146	0.04	99.73
1900	32	92178	0.03	99.76
2100	34	92212	0.04	99.80
2300	28	92240	0.03	99.83
2500	18	92258	0.02	99.85
2700	11	92269	0.01	99.86
2900	8	92277	0.00	99.87
3100	11	92288	0.01	99.88
3300	13	92301	0.01	99.89
3500	14	92315	0.02	99.91
3700	13	92328	0.01	99.92
3900	8	92336	0.00	99.93
4100	47	92383	0.05	99.98
4300	1	92384	0.00	99.98
4500	0	92384	0.00	99.98
4700	1	92385	0.00	99.98
4900	2	92387	0.00	99.99
5100	12	92399	0.01	100.00

Figure 3-3. Distribution of TSI CO Curb Idle Concentrations for All Filtered I/M Tests



TX96_PRI_CURB_IDLE_CO MIDPOINT	FREQ.	CUM. FREQ.	PCT.	CUM. PCT.
-1	0	0	0.00	0.00
1	90154	90154	97.57	97.57
3	1067	91221	1.15	98.73
5	487	91708	0.53	99.25
7	288	91996	0.31	99.56
9	335	92331	0.36	99.93
11	47	92378	0.05	99.98
13	21	92399	0.02	100.00
15	0	92399	0.00	100.00
17	0	92399	0.00	100.00

Figure 3-4. Distribution of TSI CO High Speed Concentrations for All Filtered I/M Tests

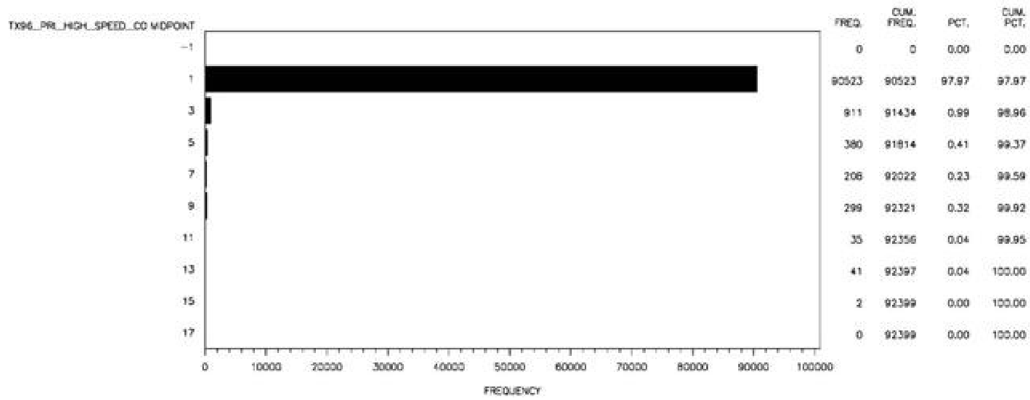


Table 3-1. Distribution of Measured CO_2 Concentrations

Emission Test Type	**Test Mode**	**Frequency**	**Percent of CO_2 Readings**		
			CO_2 < 6%	6% < CO_2 < 16%	CO2 > 16%
TSI	Curb Idle	103,574	0.43	99.44	0.14
	Fast Idle	103,574	0.23	99.63	0.14

1. The fraction of observations with both the license plate and the VIN missing was determined. 99.98% of the observations have neither VIN nor Plate missing. 0.02% of the observations have VIN present, but a missing Plate. These are the only two combinations present.
2. The validity of each 17-digit VIN was checked using the check digit of the VIN (valid on 1981 and newer VINS). Table 3-2 shows the counts of the various Check Digit results.

Table 3-2. Distribution of Check Digit Codes on Unique 17-Digit VINs in the I/M Test Records

Check Digit Code	**Description of Code**	**Frequency**	**Percent**
BADCK	Invalid Check Digit (should be 0 to 9 or X)	26	0.002
CHAR	Either I, O, or Q (invalid characters) is in the VIN string	0	0.000
ERROR	Check Digit does not agree with check digit calculation	179	0.016
OK	Check Digit agrees with check digit calculation	1,141,676	99.98
Total		1,141,881	100.00

3. Each license plate is generally associated with only a single VIN, except in the cases of vehicle sales where the seller keeps his/her plate (including vanity plates), or dealer plates which may be used with multiple vehicles. Table 3-3 below shows that 99.76% of the plates have a single VIN. The

0.21% of the plates with two or more VINs is expected due to the situations listed above.

Table 3-3. Number of VINs per Plate

VIN Count	Frequency	Percent
1	1,131,662	99.757
2	2,375	0.209
3	161	0.014
4	78	0.007
5	25	0.002
>5	120	0.011
Total	1,134,421	100.0

3.2 Inspection Statistics: Number of Vehicles Inspected by Inspection Type

The goal of this element was to tabulate inspection types and failure rates of I/M eligible vehicles in each I/M program area. The TIMS data were used to make a simple count of various types of inspections performed (TSI, ASM or OBD) and the number of vehicles that received these inspections. This is an indication of the extent to which the Texas I/M program fleet was participating in the I/M program. Counts include only emissions inspections.

3.2.1.1 Inspection Statistics

Table 3-4 shows the number of ASM, OBD, and TSI tests in each I/M program area performed during the evaluation period (January 1, 2012 through December 31, 2013).

Table 3-4. Emissions Tests per I/M Program Areas

I/M Program Area	Emission Test Type	Counts	Percent
AUS	ASM	0	0.0
	OBD	1,749,009	95.0
	TSI	92,399	5.0
	Total	1,841,408	100.0

Table 3-5 shows the number of vehicles receiving at least one I/M test during the evaluation period.

Table 3-5. Number of Vehicles Receiving At Least One Emissions Test

I/M Program Area	Emission Test Type	Counts	Percent
AUS	ASM	0	0.0
	OBD	1,082,446	94.7
	TSI	60,023	5.3
	Total	1,142,469	100.0

Table 3-6 shows the number of passes and fails and the fail fraction along with the number of emissions tests (including ASM, OBD, and TSI) performed in each I/M Program Area.

Table 3-6. Emission Test Pass/Fail Counts

I/M Program Area	Emission Test Type	Pass/Fail Status	Counts	Fail Percent
AUS	ASM	Fail	0	0.0
		Pass	0	
	OBD	Fail	92,056	5.26
		Pass	1,656,953	
	TSI	Fail	7,792	8.43
		Pass	84,607	

ERG also looked at the emission test types within I/M cycles to determine whether emission test types changed mid-cycle. For about 99.986% of the I/M cycles the same emissions test type was performed throughout the duration of the cycle, where a cycle is defined as the sequence of tests undertaken by a particular vehicle between initial and final tests.

ERG then looked at test type by model year. Figure 3-5 shows the distributions of numbers of vehicles by model year for each emission test type for the Austin I/M program area. As would be expected, there is a noticeable transition between the 1995 and 1996 model year vehicles from tailpipe testing to OBD testing. This sudden change occurs because OBD tests are conducted on 1996 and newer model year vehicles while TSI tests are conducted on 1995 and older model vehicles.

Figure 3-5. Count of Emission Test Types by Model Year for Austin

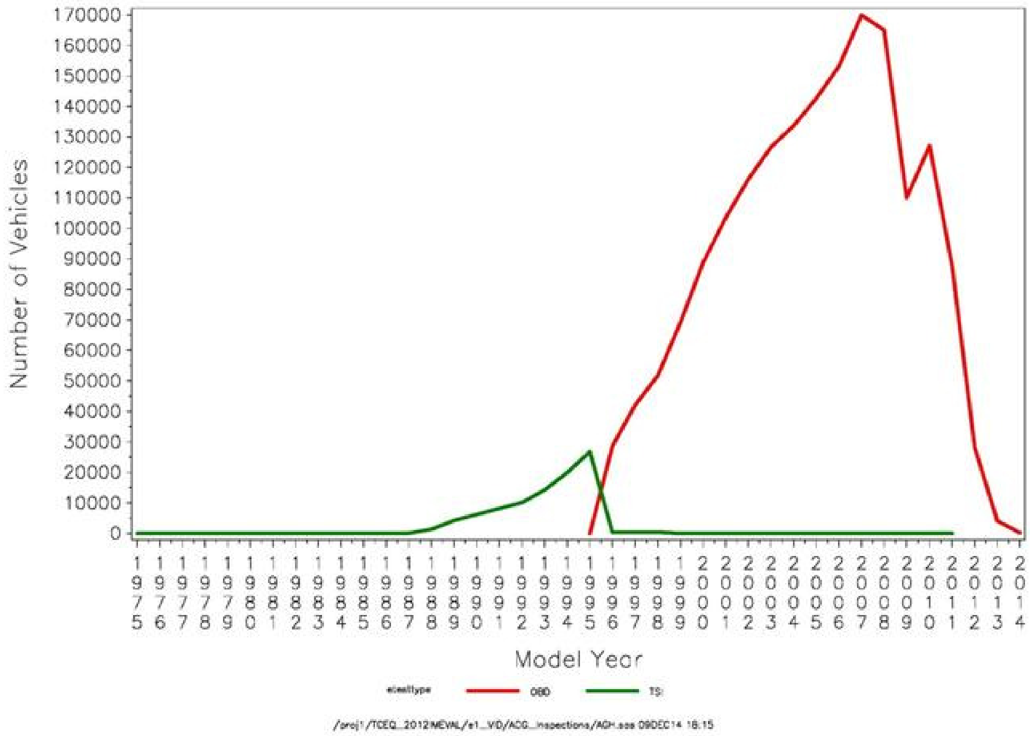
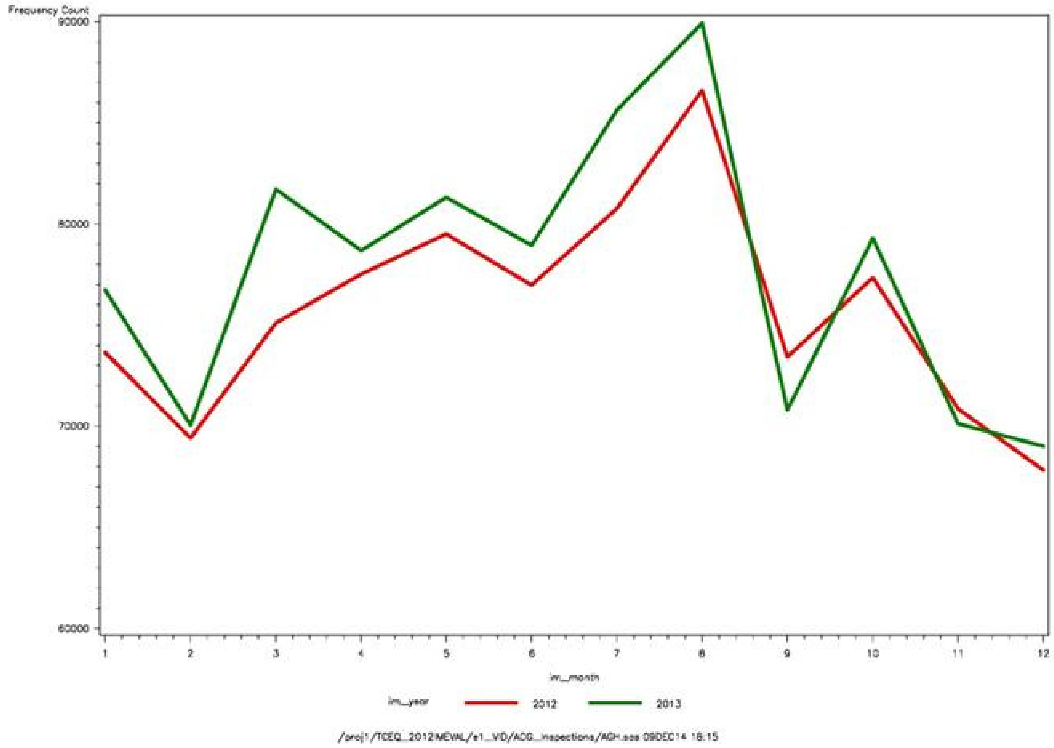


Figure 3-6 shows the number of vehicles tested by month and by year for the Austin I/M program area. The number of tests conducted each month is not the same from month to month. In Figure 3-6 the counts of vehicles tested begins in January 2012.

Figure 3-6. Emission Test by Month for Austin



3.3 Repeat I/M Failure Patterns

ERG examined the TIMS data to determine the patterns of repeat I/M failures. This illustrates the extent and properties of repairs related to the I/M program. TIMS data collected between January 1, 2012 and December 31, 2013 was used for this analysis. To distinguish amongst and handle partial and complete individual vehicle histories, ERG developed four I/M cycle categories:

1. Initial test (first time GroupID is encountered) occurred during the first three months of the dataset, but unsure whether it is a true initial test (i.e., the true initial test may have occurred prior to January 1, 2012) AND the Final test is a Certified[3] test.
2. Initial test (first time GroupID is encountered) occurred during the first three months of the dataset, but unsure whether it is a true Initial test AND the Final test is NOT a Certified test.
3. Initial test (either definition applies) occurs after the first three months of the dataset and assumed to be a true Initial test AND the Final test is a Certified test.

---

[3] In this report, the term Certified test is used to designate an I/M inspection in which the vehicle was issued a certificate, that is, a windshield sticker, for having completed and met the I/M program inspection requirements.

4. Initial test (either definition applies) occurs after the first three months of the dataset and assumed to be a true Initial test AND the Final test is NOT a Certified test.

Every vehicle that participates in the I/M program produces a brief history when it is inspected, repaired, and retested. Ideally, vehicles should be tested and pass if they are in proper working condition and if they are not, it is expected they would fail, be repaired, tested, and passed soon thereafter. If all vehicles in the inspected fleet had only one of these two possibilities, one could conclude that the accuracy of the I/M measurements and the efficacy of the repairs made to Texas vehicles were ideal. The actual test-repair sequences of real I/M programs were determined by an analysis of the TIMS data and, in general, produced many more possibilities than just the ideal two scenarios. For example, a sequence that is fail, fail, fail, pass might indicate that either the motorist is "shopping around" for a passing result, that the repairs done to the vehicle were inadequate, or that the emissions test was inaccurate.

Each vehicle was tested at an I/M station on one or more occasions. The TIMS does contain a variable that gives the type of test (Initial or Retest) and a variable that gives the result of the emissions test (Pass or Fail). However, for the purposes of determining failure patterns, ERG did not consider whether the test was designated by the TIMS as an initial or retest. For this analysis, the I/M sequences that were built by designating the first test to follow a certifying test as an initial test, and any test after that initial test, up to an including the certifying test, as a retest. Failed inspections were designated with an "F" and passes with a "P".

For each unique GroupID, the designators were concatenated in chronological order to create a sequence that describes the failure pattern that each vehicle experienced during an I/M testing cycle. For example, for a vehicle that initially failed and then passed on a re-test, the test sequence would be "FP". The frequency distribution of the resulting test sequences for completed I/M cycles (I/M Cycle Category = 3) is shown in Table 3-7.

Table 3-7. Frequency Distribution of Test Sequences for Austin for I/M Cycle Category = 3

Test Sequence	Number of Vehicles	% of Vehicles
P	1,448,553	95.2
FP	62,452	4.1
PP	6,957	0.5
FFP	2,907	0.2
FFFP	250	0.0
FF	129	0.0
PFP	213	0.0
FPP	130	0.0
FFF	74	0.0
PPP	68	0.0
FFFFP	15	0.0
Other Sequences	71	0.0
Total	1,521,819	100.0

In Table 3-7, the top two rows, which represent the two "ideal" inspection sequences, comprise more than 99% of the total distribution. However, some of the other sequences raise questions, such as, why are some of the vehicles tested a second time after they pass initially, in either program area? One explanation could be that a vehicle goes to one station and passes its emissions test, but fails its safety test. Rather than returning to the same station, the vehicle goes to another station, but needs to be completely tested again even though it failed just the safety portion at its previous test.

About 20 less common sequences accounted for the remaining 0.7% of the tested fleets in DFW and HGB. Many of these remaining sequences seem to be unlikely, and could be the result of resale vehicles, unidentified covert audit vehicles, or possibly test classification errors instead of real situations. While it may be possible to reduce the occurrence of these unlikely test sequences, the problem is relatively uncommon.

Table 3-7 showed the results for the third I/M cycle category. Tables 3-8 through 3-10 show the first, second, and fourth I/M cycle categories respectively.

The test sequences for the first I/M cycle category in Table 3-8 look very similar to the sequences in Table 3-7. Many of these cycles are probably complete and certified cycles with the true initial tests occurring in the dataset, but uncertainty remains without examining the TIMS data prior to January 1, 2012. The test sequences for the second and fourth I/M Cycle Categories in Tables 3-9 and 3-10 consist of many more sequences that end in a Fail. As expected, these are not certified cycles. Approximately 75% of the sequences are either a single Fail or Fail-Fail. The remaining percentage of single, uncertified passes may be due to grouping errors. It is not possible to judge if these observations warrant further investigation at this point; therefore, the actual records for these sequences have been provided to the TCEQ.

Table 3-8. Frequency Distribution of Test Sequences for I/M Cycle Category=1

Test Sequence	Vehicle Frequency	% of Vehicles
P	195,046	94.1
FP	10,275	5.0
PP	1,112	0.5
FFP	572	0.3
FFFP	62	0.0
PFP	42	0.0
Other Sequences	100	0.0
Total	207,209	100.0

Table 3-9. Frequency Distribution of Test Sequences for I/M Cycle Category=2

Test Sequence	Vehicle Frequency	% of Vehicles
F	1,459	70.2
P	376	18.1
FF	180	8.7
PP	3	0.1
FP	23	1.1
FFF	14	0.7
Other Sequences	23	1.1
Total	2,078	100.0

Table 3-10. Frequency Distribution of Test Sequences for I/M Cycle Category=4

Test Sequence	Vehicle Frequency	% of Vehicles
F	13,555	68.3
P	4,658	23.5
FF	1,165	5.9
PP	72	0.4
FP	177	0.9
PF	58	0.3
Other Sequences	156	0.8
Total	19,841	100.0

3.4 Emissions Analyzer Data Quality

The goal of this task was to demonstrate the accuracy of the emissions inspection methods. The following four I/M analyzer checks were made using Texas TIMS data: Drift, Dilution Correction Factors, Gas Audits, and Lockouts.

3.4.1 Analyzer Drift

Texas I/M program emissions analyzers require 72-hour calibrations. The calibration is done using the analyzer to measure a bottled calibration gas mixture with a concentration that is known within a specified precision. Before a calibration is performed, a pre-calibration measurement on the calibration gas is made and recorded in the TIMS for HC, CO, O_2, and CO_2 gases (Austin's TSI analyzers do not record NOx). The difference between the pre-calibration analyzer reading and the labeled concentration of the gas mixture is a direct measure of instrument drift. If the analyzer has not drifted since the last calibration, its readings for the calibration gas will be close to the bottle label value, and little calibration adjustment will be necessary. This fact can be used to develop an indicator of analyzer calibration stability. Analyzers that consistently retain calibrations can be expected to produce more accurate measures of vehicle emissions than those that drift greatly. If the difference between the bottle label value and the pre-calibration analyzer reading is very large, then it is presumed that some of the emissions measurements made during the previous 72 hours were less accurate than desirable.

3.4.1.1 Calibration Procedures and Specifications

In each 72-hour calibration, the analyzer first records pre-calibration readings for HC, CO, and CO_2, for zero, low-span, and mid-span bottle gases, and for O_2 with ambient air. The analyzer is then calibrated on the mid-span gases to within 1% of the bottle gas values. Next, the analyzer is tested on the low-span gases, and must fall within 2% of the bottle gas value. If the analyzer cannot be brought within specifications during the calibration, the instrument is automatically prohibited from performing any portion of any I/M test until it is successfully adjusted.

Table 3-11 shows the specified bottle gas values for the low-span and mid-span portions of the calibration. The bottled gases are permitted a 5% blend tolerance, which is also shown in the table. Finally, the table shows the specified accuracy of the analyzer for I/M inspections for each pollutant and gas level. These tolerances for I/M inspections are less stringent than the 1% mid-span and 2% low-span tolerances that are used for calibrations. The I/M inspection tolerances are applicable to this analysis of pre-calibration readings since the concern here is with whether analyzer drift affected I/M inspection results just prior to calibration. As an example from the table, the low-span HC bottle gas concentration is specified to be 200 ppm, but may range between 190 and 210 ppm. If a bottle gas labeled to contain 195 ppm HC were used for a calibration, the analyzer would be required to read between 189 and 201 ppm in order to meet the specification.

Table 3-11. Calibration Span Gas Values and Tolerances

Gas	Specified Bottle Gas Concentration	Bottle Gas Blend Tolerance	Analyzer Tolerance for I/M Inspections
Zero Gas			
HC (ppm)	<1	Not applicable for zero gases	±4
CO (%)	<0.01		±0.02
CO_2 (%)	<4.0		±0.3
O_2 (%)	20.7		±1.04
Low-Span Bottle Gas			
HC (ppm)	200	±10	±6
CO (%)	0.5	±0.025	±0.02
CO_2 (%)	6.0	±0.3	±0.3
Mid-Span Bottle Gas			
HC (ppm)	3200	±160	±160
CO (%)	8.0	±0.4	±0.24
CO_2 (%)	12.0	±0.6	±0.36

The actual concentrations of the bottle gases used in each calibration are recorded in the TIMS. More than 99.9% of calibration records include bottle gas label concentrations within the tolerances listed in Table 3-12. However, the remaining small fraction of records include some surprisingly high and low bottle gas values, such as about 7 records with zero percent or ppm for each of the low-span and mid-span concentrations. It is possible that the bottle gas concentration was entered incorrectly into the TIMS, or that the outlying values represent real bottle gas mixtures that were occasionally used. In either case, the calibration results are called into question when the analyzer reading is compared to out-of-specification bottle gas label values. To eliminate this issue in future calibration records, ERG recommends that the TCEQ restrict the inspector-entered bottle gas values to a range that corresponds to the specifications. Thus, the analyzer software would not allow a calibration to proceed unless reasonable bottle gas values were entered.

3.4.1.2 Results

Span test calibration records from the TIMS between January 1, 2012 and December 31, 2013 were available for this analysis. Records with a PEF result of "0" were deleted, since these records appeared to contain no calibration information, leaving 70,314 records from Austin stations in the dataset. Records with zero or missing information were checked for, and none were found.

Figures 3-7 through 3-17 each show the distribution of the difference between the analyzer reading and the labeled value of the bottle gas, for one gas type/concentration level combination. For the zero level readings, the difference between zero and the recorded concentration is shown. For the O_2 plots, the 0% and 20.7% data are plotted separately because the tolerance for the analyzer is tighter at 0% O_2 than at 20.7% O_2.

All of the distributions show a clear peak at zero, indicating that many analyzers drift very little between 72-hour calibrations. For many of the figures, almost the entire range of readings fell within the tolerance for that gas type/concentration level. The results that are shown in these figures are similar to those that were seen for the DFW/HGB programs.

Figure 3-7. Distribution of Difference Between Zero and HC Pre-Calibration Reading

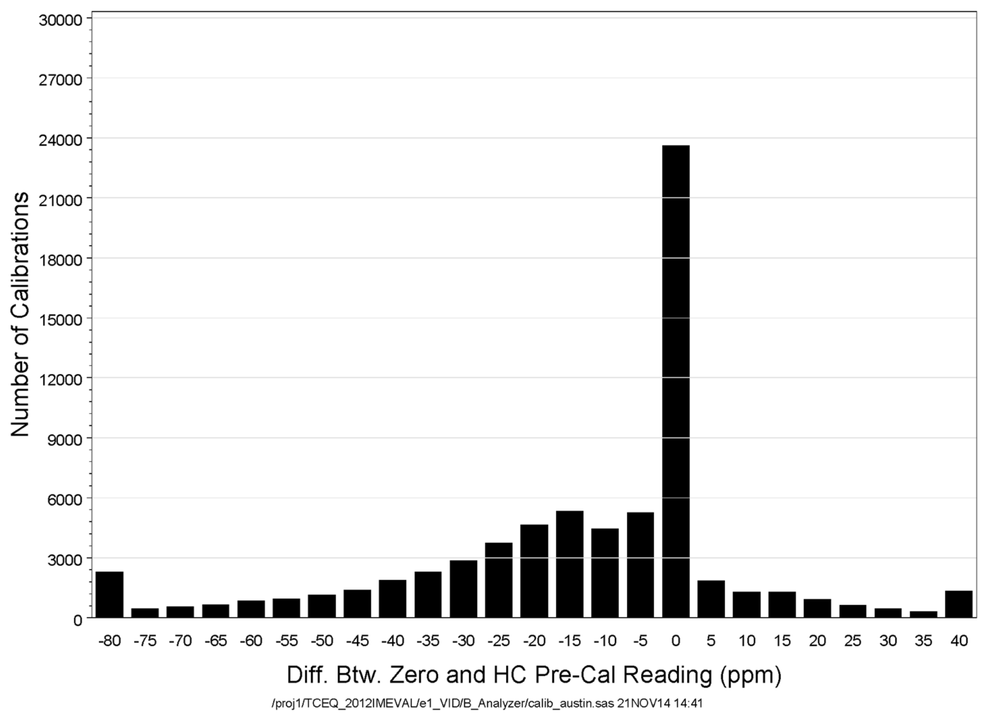


Figure 3-8. Distribution of Difference Between Zero and CO Pre-Calibration Reading

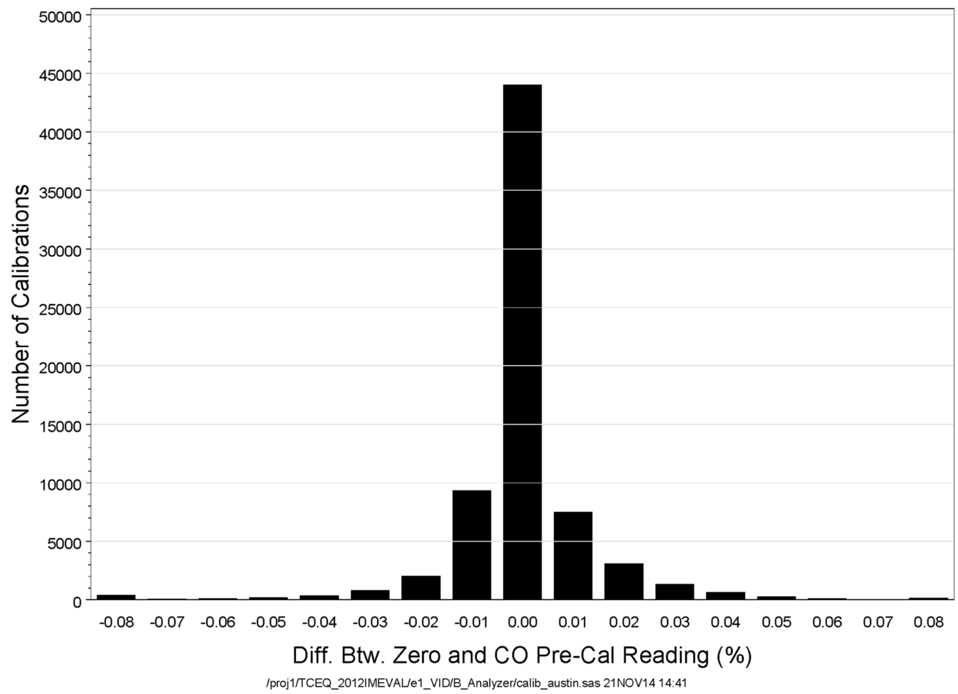


Figure 3-9. Distribution of Difference Between Zero and CO_2 Pre-Calibration Reading

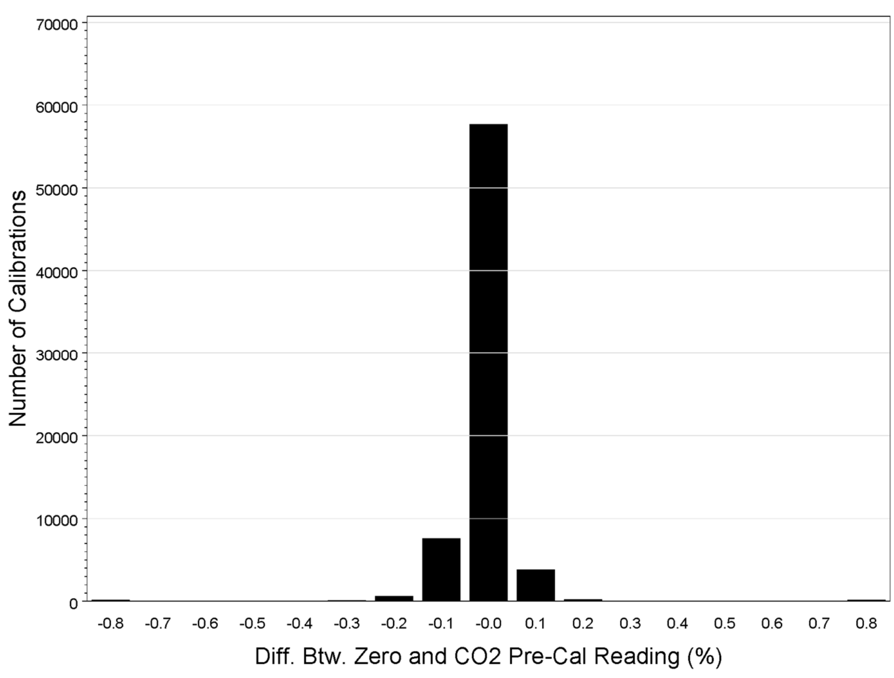


Figure 3-10. Distribution of Difference Between Zero and O_2 Pre-Calibration Reading

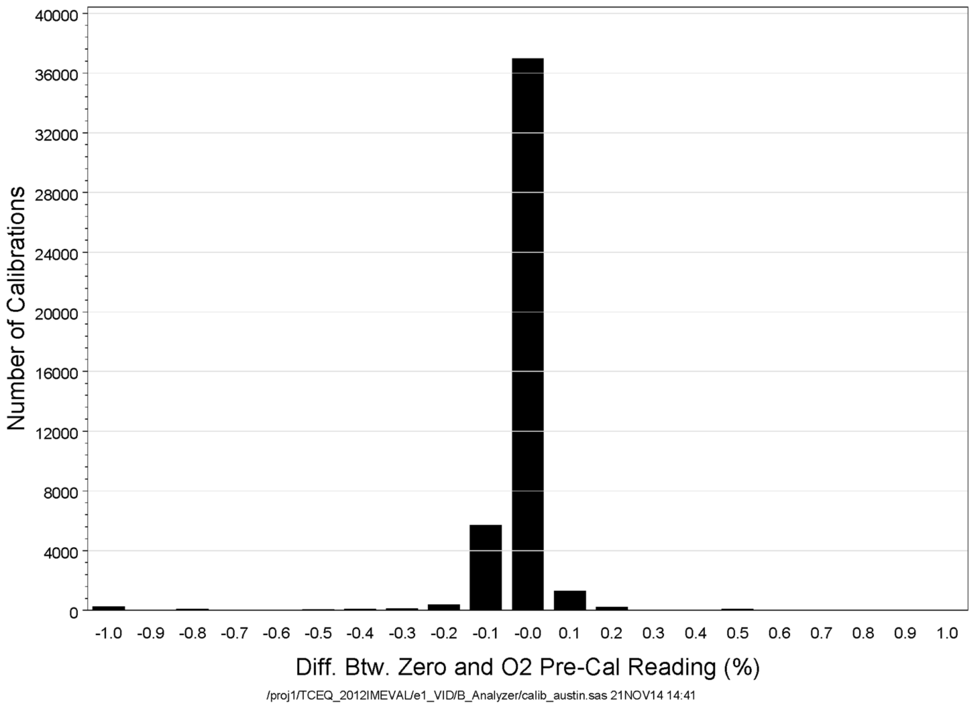


Figure 3-11. Distribution of Difference Between 20.7% and O_2 Pre-Calibration Reading

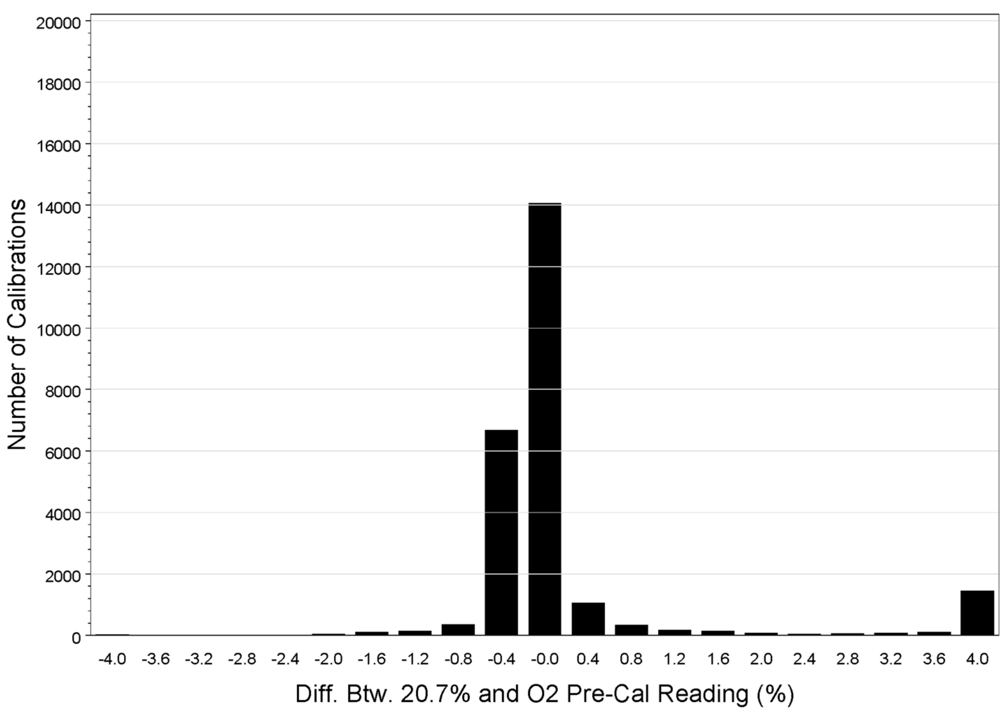


Figure 3-12. Distribution of Difference Between Low-Span Bottle and HC Pre-Calibration Reading

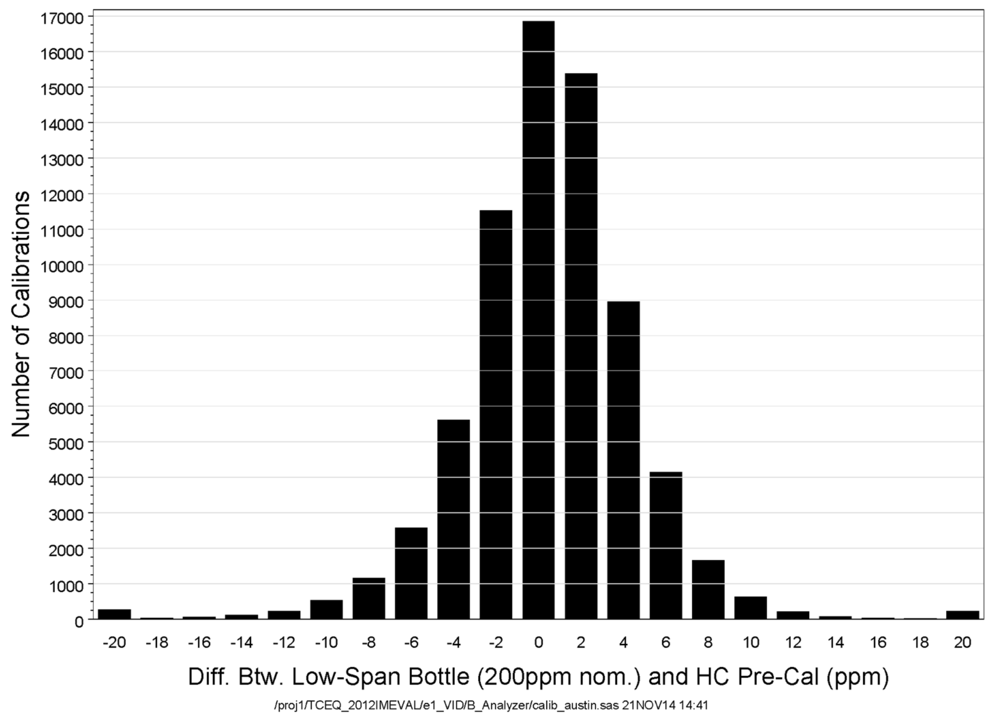


Figure 3-13. Distribution of Difference Between Low-Span Bottle and CO Pre-Calibration Reading

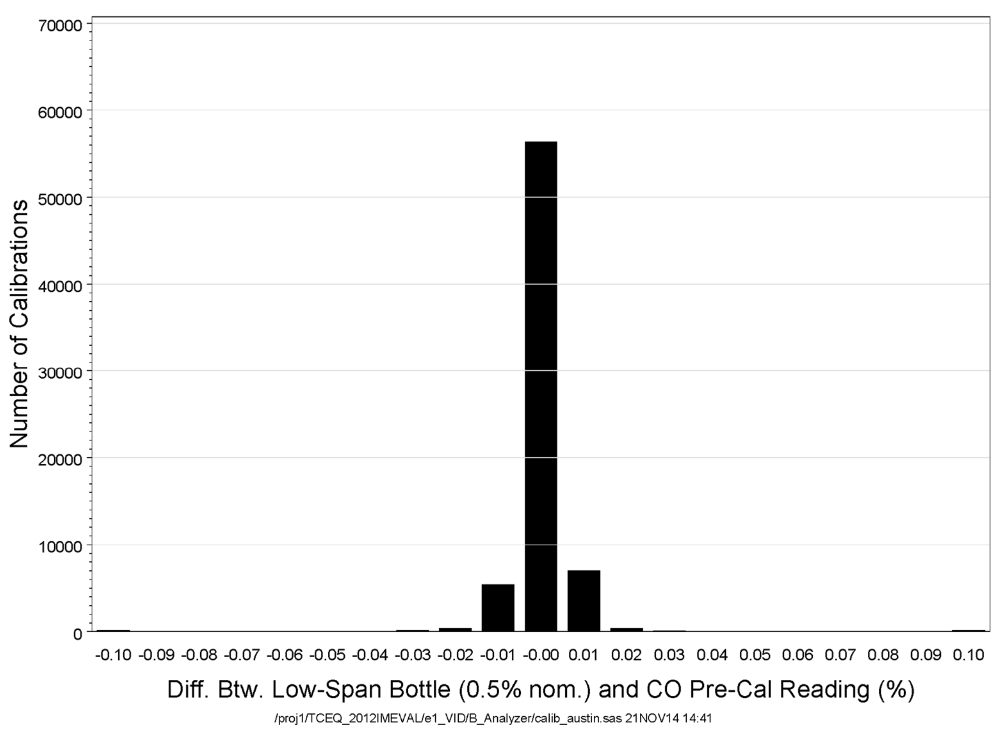


Figure 3-14. Distribution of Difference Between Low-Span Bottle and CO_2 Pre-Calibration Reading

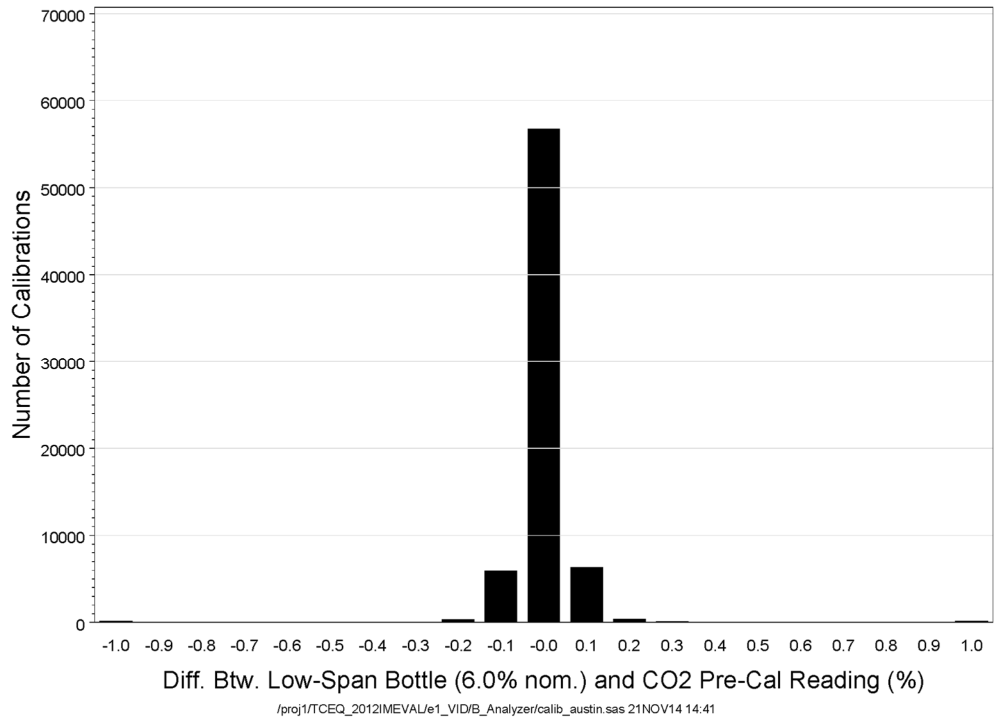


Figure 3-15. Distribution of Difference Between Mid-Span Bottle and HC Pre-Calibration Reading

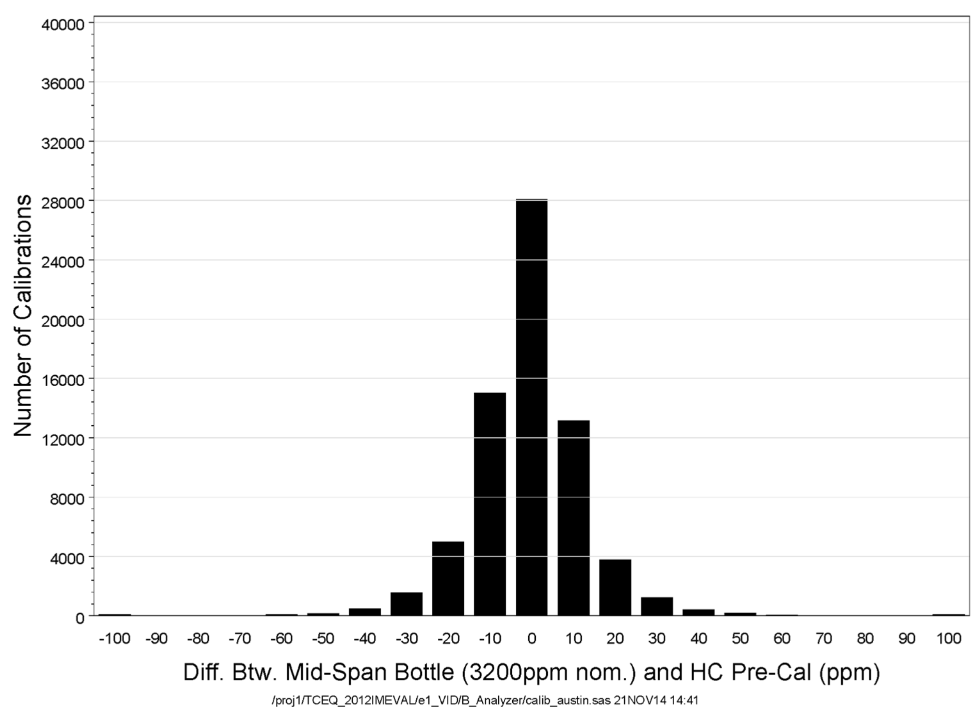


Figure 3-16. Distribution of Difference Between Mid-Span Bottle and CO Pre-Calibration Reading

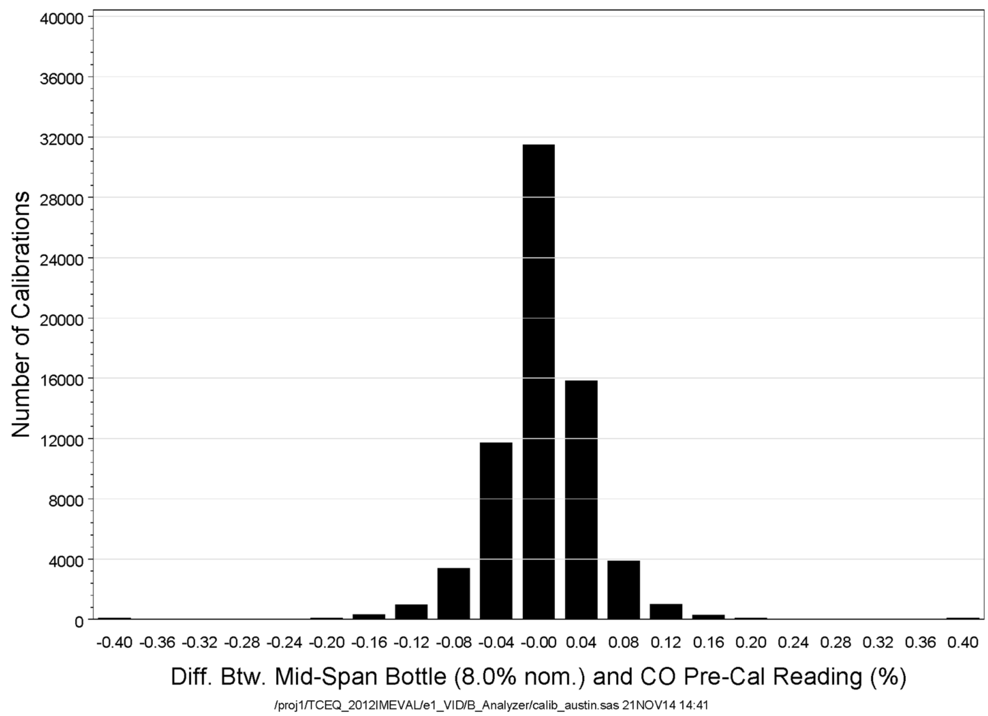


Figure 3-17. Distribution of Difference Between Mid-Span Bottle and CO_2 Pre-Calibration Reading

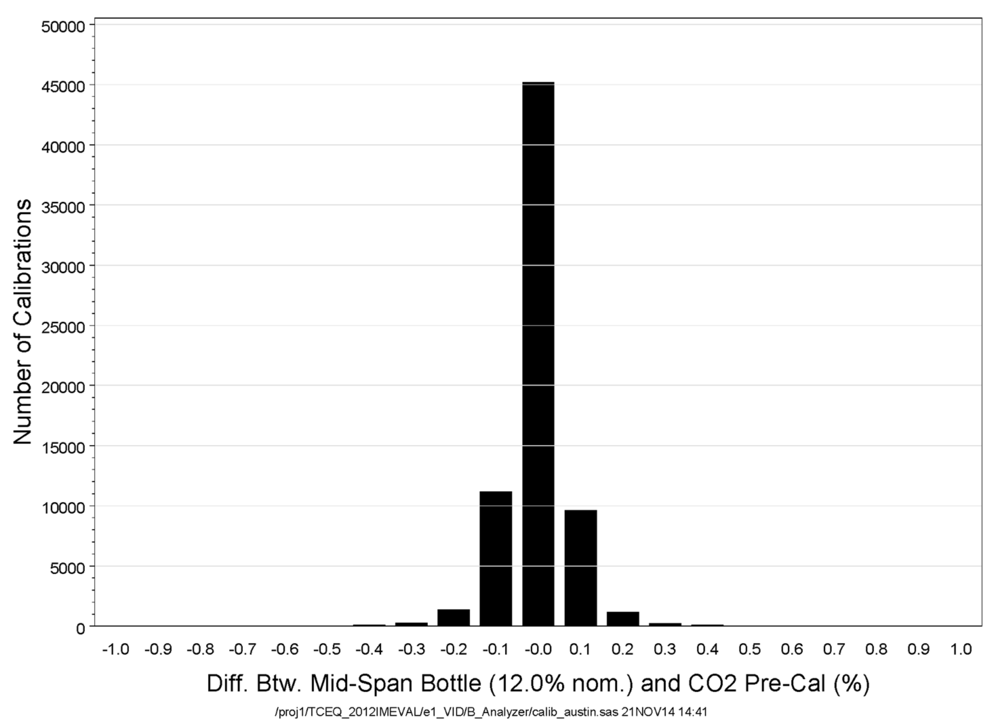


Table 3-12 shows the specified value and tolerance for each gas type/concentration level, the total number of pre-calibration records available at that level, the percent of records whose values fell within the tolerance bounds, and finally, the amount of difference from the specified value that would include 90% of calibration records (the 90th percentile).

Note that the total record counts vary by concentration level in Table 3-12. About 70,300 records were available at the zero level, but only 69,400 records at the mid-span level. This reduction is a result of calibration records with zero pre-calibration values but no mid-span values. It is important to record the pre-calibration readings so that analyzer drift can be tracked, but it appears that not all portions of the pre-calibration data are recorded at every calibration event.

For almost all gas type/concentration level combinations, more than 90% of pre-calibration records fell within the tolerance of the analyzer. The exception is the zero level HC, where only 40% of records were within tolerance (the wide distribution can be seen in Figure 3-7 as well). This indicates that results for more than 90% of I/M inspections performed just before the calibration can be expected to be within instrument tolerance (except for very low values of HC). This is just higher than the 86% that was found for the DFW/HGB areas.

Table 3-12. Number and Percent of Pre-Calibration Records Occurring Within Analyzer Tolerance

Gas	Specification	Total Number of Pre-Cal Records	Within Tolerance		90th Percentile
			N	%	
Zero Gas					
HC (ppm)	0±4	70,314	27,756	39.5	50
CO (%)	0.00±0.02	70,314	65,950	93.8	0.02
CO_2 (%)	0.0±0.3	70,314	69,920	99.4	0.1
O_2 (%)	0.0±0.1	45,403	43,944	96.8	0.1
O_2 (%)	20.7±1.04	24,911	22,523	90.4	0.9
Low-Span Gas					
HC (ppm)	200±6	70,313	64,046	91.1	6
CO (%)	0.50±0.02	70,314	68,680	97.7	0.01
CO_2 (%)	6.0±0.3	70,311	69,868	99.4	0.1
Mid-Span Gas					
HC (ppm)	3200±160	69,407	69,341	99.9	21
CO (%)	8.00±0.24	69,407	69,072	99.5	0.07
CO_2 (%)	12.00±0.36	69,407	68,959	99.4	0.1

3.4.2 Analyzer Dilution Correction Factors

For every TSI emissions test, a dilution correction factor based on the measured CO and CO_2 concentration is calculated. Dilution correction factors (DCFs) can also be calculated based on the measured O_2 concentration. The dilution correction factors from these two separate sources of tailpipe emissions should be within agreement with a relatively small tolerance. With those emissions tests where the DCFs are not in substantial agreement, there is question about the accuracy of the emissions test. The analysis does not indicate which emission is in error but indicates that something is wrong with the CO, CO_2, or O_2 measurements. Unless all three of these pollutants are in agreement with respect to their corresponding dilution correction factors, the HC, CO, and NO_x measurements reported by the instrument are in question. [Section 4.2.1.3 of Reference 1]

The measurement of exhaust emissions concentrations can be confounded by the dilution of the exhaust gas by non-optimal probe placement, leaking exhaust systems, cylinder misfires, and excess oxygen from air pumps. The Texas I/M program analyzers quantify the degree of dilution for each TSI inspection using measured CO and CO_2 concentrations to calculate a DCF. For this analysis, the CO/CO_2 DCFs were recalculated for the TSI inspections in the TIMS.

The CO/CO_2 DCFs are the official dilution correction factors used for the emissions test; however, DCFs can also be calculated using the O_2 concentration measured at each emissions test. A comparison of CO/CO_2 DCFs with O_2 DCFs is just another way to check the emissions instruments. Therefore, ERG also calculated DCFs based on the measured O_2 concentration. The dilution corrections reported in the TIMS, the CO/CO_2 dilution corrections calculated by ERG, and the O_2 dilution corrections calculated by ERG should be in agreement with a relatively small tolerance. This analysis does not necessarily indicate which emission is in error, but does indicate that something is wrong with the CO, CO_2, or O_2 measurements. Unless all three of these pollutants are in agreement with respect to their corresponding dilution correction factors, the resulting HC, CO, and NO_x measurements reported by the instrument are in question.

3.4.2.1 Background

Assuming stoichiometric combustion of gasoline, an exhaust dilution correction factor can be estimated using a carbon mass-balance and the measurements of CO and CO_2. These constituents are measured in the non-dispersive infrared bench of the analyzer. The equations are based on the average composition of gasoline. First, define the variable x:

$$x = \frac{CO_2}{CO_2 + CO}$$

where CO_2 and CO values are in percent. Then the dilution factor, DCFCO/CO_2, is as follows:

$$DCF_{CO/CO2} = 100\frac{x/(4.64 + 1.88x)}{CO_2}$$

If a fuel other than gasoline were used, the 4.64 constant would be different. However, only gasoline-fueled vehicles will be considered in this analysis.

In addition, many emissions analyzers also measure exhaust gas oxygen concentration with an electrochemical cell. Assuming an ambient air oxygen concentration of 20.9%, the exhaust oxygen measurement can also be used to estimate dilution in the exhaust. A dilution correction factor based on the measured oxygen concentration is:

$$dcf_{O_2} = \frac{20.9}{20.9 - O_2}$$

This relationship assumes that the tailpipe oxygen concentration for stoichiometric combustion and no air in-leakage is 0.0% O_2. Field measurements indicate that new vehicles with no exhaust system leaks and operating at stoichiometric air/fuel ratio have 0.0% tailpipe oxygen concentrations.

If CO, CO_2, and O_2 are measured correctly, the independent DCFs (CO/CO_2 and O_2) for each vehicle inspection should agree well with each other. Previous studies have indicated that the difference between the two DCFs should be no larger than about ±0.14 [Reference 1].

3.4.2.2 Results

For this analysis, vehicle inspection records from the TIMS for vehicles tested in the Austin area were used. Results for 101,993 inspections of gasoline-fueled vehicles that received the two-speed idle (TSI) test were available. Any records with flags that indicated the inspection had been aborted, timed out, or ended due to a dilution condition were deleted. Also, any records with zero or missing values for CO_2 were removed from the database, since the presence of CO_2 indicates that combustion was taking place and being recorded. This resulted in a dataset with 101,859 records for the low-idle TSI inspection, and 101,929 records for the high-idle TSI inspection.

The CO/CO_2-based DCF and the O_2-based DCF were calculated for each inspection record, and then plotted against each other. Figure 3-18 shows a plot of the

TSI Low Idle DCF based on CO/CO_2 versus the TSI Low Idle DCF based on O_2 for each TSI Low Idle test. Figure 3-19 shows a similar plot for TSI High Idle inspections. In both plots, most of the points fall near the 1:1 line as expected, and the degree of scatter around the 1:1 line is relatively low. However, in addition to the points clustered on the 1:1 line, the plots also show a smaller horizontal ray (DCF $CO/CO_2 \approx 1$ while DCFO_2 increases) and a vertical ray (DCF $O_2 \approx 1$ while DCF CO/CO_2 increases). Points at a distance from the 1:1 line may represent analyzer sensors for CO, CO_2, or O_2 that are broken or out of calibration, data entry errors, or other anomalies. Some of the reasons for these out-of-line points will be discussed in further detail in the sub-sections which follow.

Figure 3-18. Comparison of Low-Speed Idle TSI DCF CO/CO_2 and DCF O_2

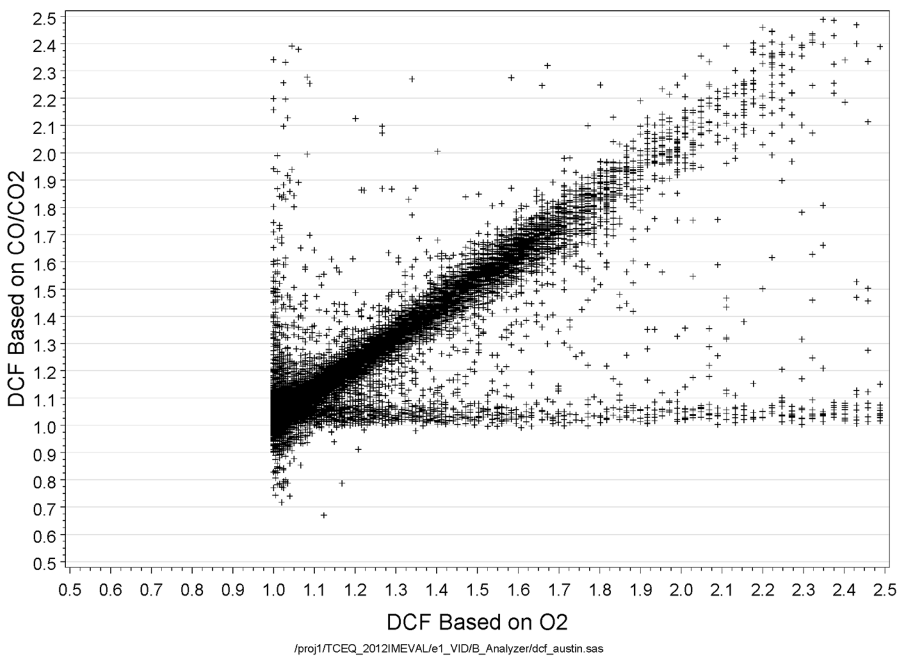
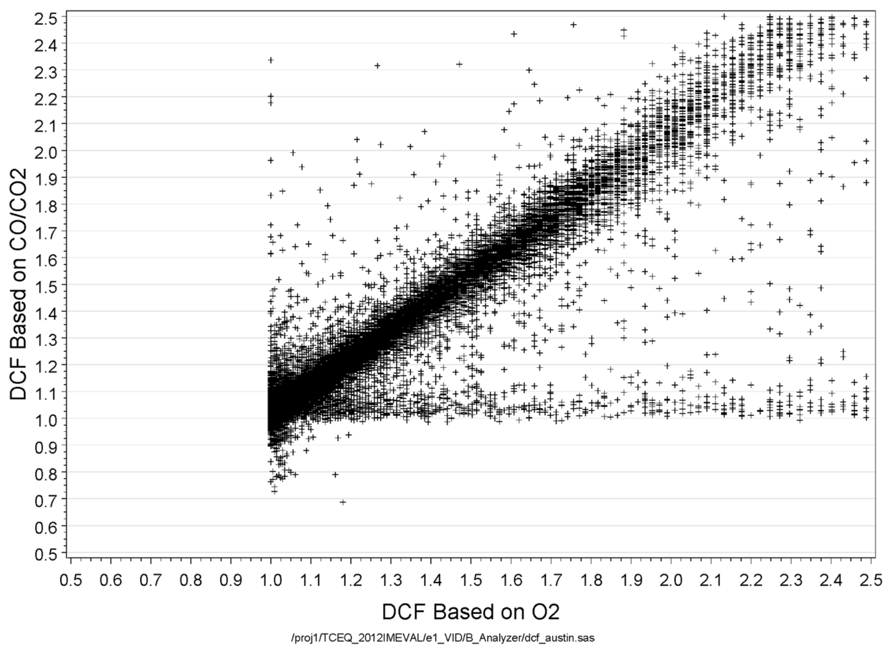


Figure 3-19. Comparison of High-Speed Idle TSI DCF CO/CO_2 and DCF O_2



The information presented graphically in Figures 3-18 and 3-19 is quantified in Table 3-13. For each inspection record, the difference between the CO/CO_2-based DCF and the O_2-based DCF was calculated. The table shows the number and percentage of records that fall into six levels of DCF difference, for each type of inspection. As noted above, previous studies have found that this difference should be no more than about ±0.14. It can be seen from Table 3-13 that for the TSI inspection records, 95% have a difference of less than 0.14. This is somewhat better than the result of 83% that was found for TSI inspection records in the DFW/HGB programs.

Table 3-13. Distribution of Differences Between DCF CO/CO_2 and DCF O_2

Test Type	<0.01	0.01-0.14	0.14-0.3	0.3-1.0	1-10	>10	Total
TSI Low	16,330 16.0%	80,165 78.7%	1,455 1.4%	629 0.6%	1,441 1.4%	1,839 1.8%	101,859 100.0%
TSI High	15,998 15.7%	81,252 79.7%	821 0.8%	568 0.6%	1,438 1.4%	1,852 1.8%	101,929 100.0%

The TIMS record for each inspection contains an identification number for the analyzer used to perform the inspection. The first two characters of the analyzer identification number indicate the manufacturer of the analyzer. The distribution of differences between the DCF CO/CO_2 and the DCF O_2 (both calculated by ERG, not from the TIMS) were compared by analyzer manufacturer, as shown in Table 3-14. The ESP rate of differences of less than 0.14 is near 93%, while the WW rate of differences of less than 0.14 is above 98%.

Table 3-14. Distribution of Differences Between DCF CO/CO_2 and DCF O_2 by Analyzer Manufacturer, for TSI Low Inspections

Analyzer Mfg. ID	<0.01	0.01-0.14	0.14-0.3	0.3-1.0	1-10	>10	Total
ESP	13,597 19.9%	50,005 73.0%	1,070 1.6%	529 0.8%	1,397 2.0%	1,777 2.6%	68,487 100.0%
WW	2,733 8.2%	30,160 90.0%	385 1.1%	100 0.3%	44 0.1%	62 0.2%	33,506 100.0%

3.4.2.3 O2 Emissions Concentration Anomalies

One factor that was found to cause problems with the DCF calculations was inaccuracy in the reported O2 emissions concentrations. The tailpipe oxygen concentration for stoichiometric combustion and no air in-leakage would be 0.0% O2, while the ambient air concentration of O2 is approximately 20.9%. The percent of otherwise-valid inspection records that included O2 concentrations greater than 20.5% is shown in Table 3-15, for both test conditions. From the table, about 1.4% of TSI records included suspicious O2 concentrations, with tailpipe exhaust O2 concentrations very close to or equal to ambient O2 concentrations (this result was closer to 8% in the DFW/HGB program areas). These will cause the O2-based DCF to have a very high (or undefined, when O2 equaled exactly 20.9%) value.

Table 3-15. Number and Percent of Suspicious O_2 Concentrations by Test Mode

Test Type	O2 >20.5%	O2 <20.5%	Total
TSI Low	1,477 1.4%	100,389 98.6%	101,866 100.0%
TSI High	1,486 1.5%	100,449 98.5%	101,935 100.0%

It was also found that the rate of suspicious O_2 concentrations was much higher for one of the analyzer manufacturers than for the other, as shown in Table 3-16. The ESP analyzers were responsible for almost all of the suspicious O_2 concentrations.

Table 3-16. Number and Percent of Suspicious O_2 Concentrations (O_2 >20.5%), by Analyzer Manufacturer

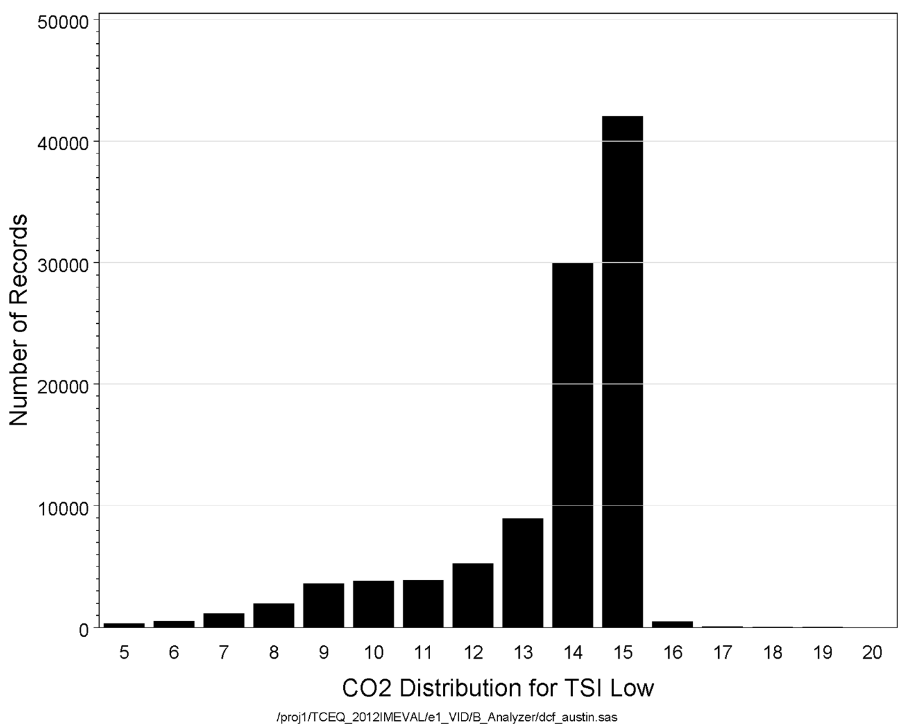
Analyzer Mfg. ID	O2 >20.5%	O2 <20.5%	Total
ESP	1,429 2.1%	66,946 97.9%	68,375 100.0%
WW	48 0.1%	33,443 99.9%	33,491 100.0%

3.4.2.4 CO_2 Emissions Concentration Anomalies

Another factor that was found to cause problems with the DCF calculations was inaccuracy in the reported CO_2 emissions concentrations. The tailpipe carbon dioxide concentration for stoichiometric combustion and no air in-leakage should be 15.6% CO_2. CO_2 values lower than 15.6% can occur because of air in-leakage or because some of the carbon is in the form of CO or HC. Any CO_2 values higher than 15.6% would be cause for suspicion.

The distribution of CO_2 values for the TSI Low Idle inspection is shown in Figure 3-20. It can be seen from the figure that the CO_2 values are concentrated around 15%, as expected. However, a small fraction of CO_2 values do exceed 16%, for 0.07% of TSI Low Idle inspection records (73 records out of 100,000 total records). These records were investigated further.

Figure 3-20. Distribution of CO_2 Values for TSI Low Idle Inspection



It was found that the high CO_2 concentrations all resulted from inspections by one analyzer manufacturer, ESP, while none resulted from inspections by the WW analyzers, as shown in Table 3-17.

Table 3-17. Number and Percent of Suspicious CO_2 Concentrations (CO_2 >16.5%), by Analyzer Manufacturer, for TSI Low Idle

Analyzer Mfg. ID	CO2 >16.5%	CO2 <16.5%	Total
ESP	68,398 99.9%	73 0.11%	68,487 100.0%
WW	33,506 100.0%	- 0.0%	33,506 100.0%

The high-CO_2 inspection records were matched to calibration records (described in Section 3.4.1) to find instances where the analyzer responsible for the high-CO_2 inspection record was calibrated within the following 24 hours. The mid-span pre-calibration CO_2 readings were then inspected to determine whether the high-CO_2 records could be attributed to out-of-calibration analyzers. However, only four matched records were found, so no trends were apparent.

One consequence of recording a CO_2 concentration greater than 15.6% is that the CO/CO_2-based dilution correction factor will be less than 1, indicating a "concentration" condition, rather than a dilution condition. Records with very high CO concentrations will also have a DCF of less than 1. In the TIMS, these DCFs are rounded up to 1; no DCFs of less than 1 are stored. However, just as a high DCF (greater than 1) can act as a flag for a problematic dilution condition, a low DCF (less than 1) can also provide a useful warning that inspection results may be suspect. The equation for the O_2-based DCFs does not allow the O_2 DCF to fall below 1. However, low CO/CO_2-based DCFs were seen in Figures 3-26 and 3-27. For the TSI Low Idle inspection, no records have DCF CO/CO_2 less than 0.65, and only 160 records have DCF CO/CO_2 between 0.65 and 0.95 (0.2% of total inspection records). This is a lower rate than the 1.1% that was seen for the DFW/HGB program areas.

3.4.2.5 Extra Vertical and Horizontal Rays

It was noted above that Figures 3-18 and 3-19 with the CO/CO_2-based DCF plotted against the O_2-based DCF for ASM inspections, appear to contain three distinct "rays". The majority of points fall near the diagonal 1:1 line, but there is a substantial set of points near a horizontal line at DCF CO/CO_2 =1, and a smaller set of points near a vertical at DCF O_2=1. To investigate the reasons for the rays, the set of inspection records for the TSI Low Idle test was subdivided into four categories: points falling along each of the diagonal, horizontal rays, vertical rays, and other points that didn't fall neatly into any of the rays. The distributions of emissions concentrations for O_2, CO_2, and CO for records comprising the three rays were then compared, as shown in Figures 3-21 through 3-23.

Figure 3-21 shows that the horizontal ray is comprised of inspection records with high O_2 concentrations. Almost all of the records with O_2 concentrations greater than

4% fall on that ray. (The horizontal ray results from records with high DCF O_2 values and DCF CO/CO_2 values near 1.) A high O_2 concentration results in a high DCF O_2 value, and would seem to indicate a dilution condition (air entering the exhaust stream to add O_2 to the sample), but the DCF CO/CO_2 values remain around 1 in the horizontal ray, indicating that the CO and CO_2 emissions are not being diluted. Figures 3-22 and 3-23 show that the distributions of CO_2 and CO concentration for the horizontal ray are very similar to the distributions for the diagonal ray.

The figures show the opposite result for the vertical ray (comprised of records with high DCF CO/CO_2 and DCF O_2 near 1). Figure 3-21 shows that the O_2 concentration distribution for the vertical ray is similar to that of the diagonal ray. Figure 3-22 shows that the CO_2 concentration for records in the vertical ray was almost always less than 10%, instead of the 15% seen for the diagonal ray. Figure 3-31 shows that the CO concentration for records in the vertical and horizontal rays was similar to that of records in the diagonal ray.

Overall, Figures 3-21, 3-22, and 3-23 indicate the records in each ray were systematically different from the records in each other ray.

Figure 3-21. Distribution of O2 Concentrations, by "Ray"

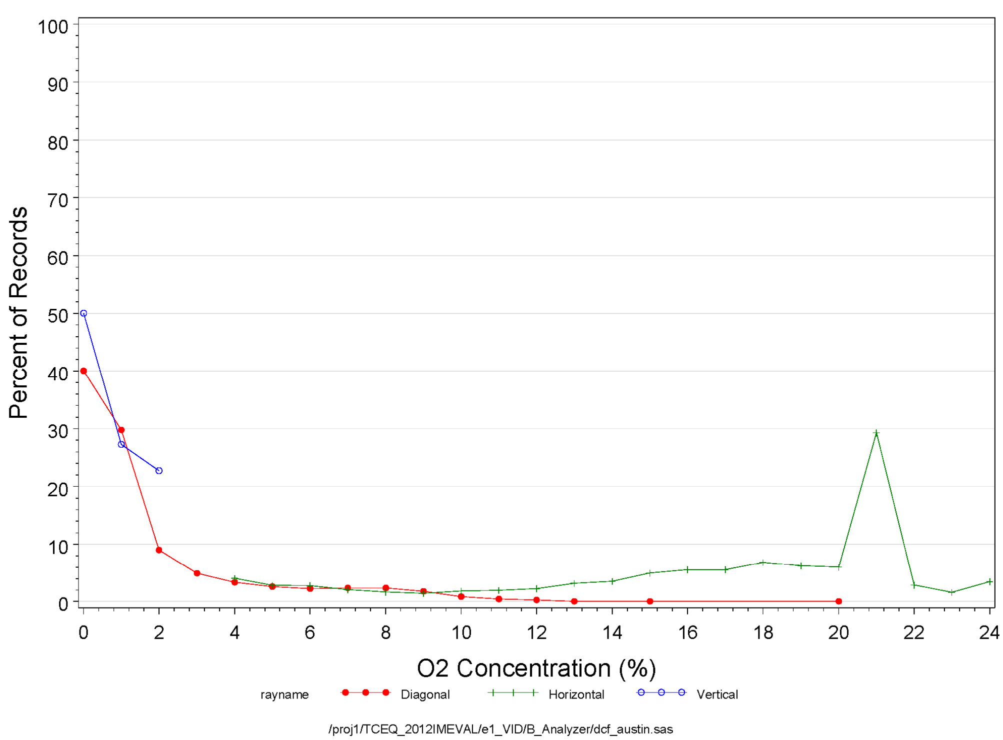


Figure 3-22. Distribution of CO_2 Concentrations, by “Ray”

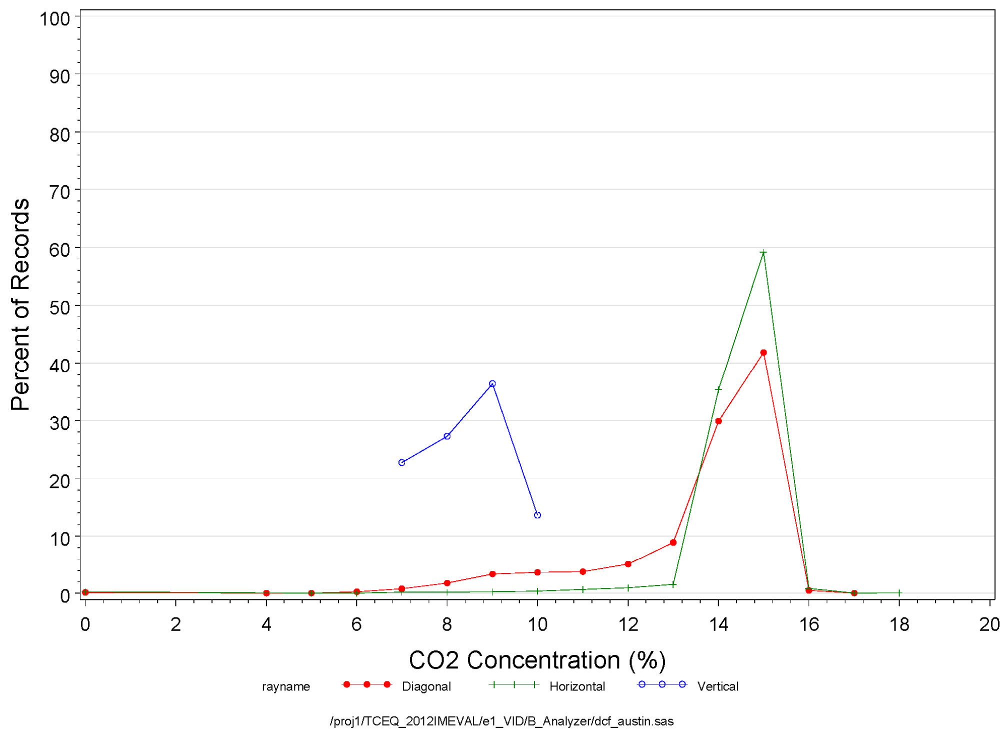
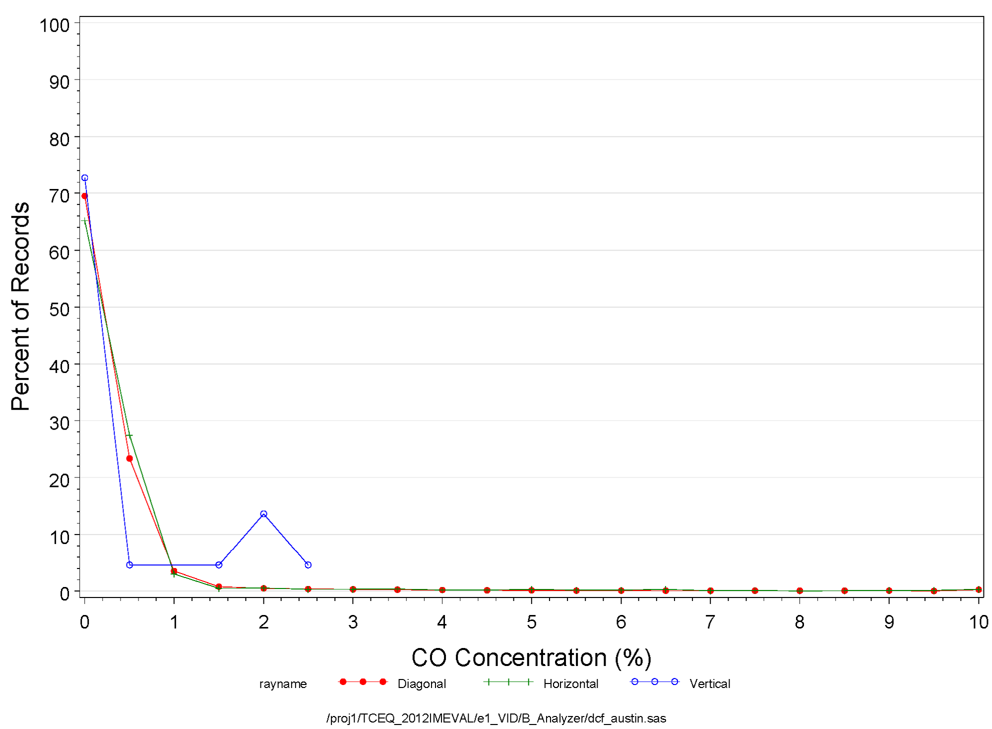


Figure 3-23. Distribution of CO Concentrations, by “Ray”



The distribution of records into each ray-group was tabulated by analyzer manufacturer, as shown in Table 3-18 below. As expected, the records from ESP analyzers contributed a large portion of the records for the horizontal ray. In Figure 3-21 it was seen that this ray includes most of the records with O_2 concentrations near 20.9% (ambient concentration), and in Table 3-16 it was seen that the ESP analyzers contributed the majority of the records with the high O_2 concentrations. Table 3-18 also shows that the ESP analyzers were responsible for a greater proportion of the records in the “Other” column than were the WW analyzers. The “Other” group includes all records that didn’t fall neatly into one of the rays; these records represent scatter in the data, rather than a systematic problem as represented by the vertical and horizontal rays. It is more difficult to see trends among the analyzer manufacturers for the vertical ray, since there were many fewer records in that ray.

Table 3-18. Number and Percent of Records in Each Ray by Analyzer Manufacturer, for TSI Low Idle

Analyzer Mfg. ID	Vertical	Horizontal	Diagonal	Other	Total
ESP	10 0.0%	2,565 3.7%	63,706 93.0%	2,206 3.2%	68,487 100.0%
WW	12 0.0%	83 0.2%	32,903 98.2%	508 1.5%	33,506 100.0%

3.4.3 Analyzer Gas Audits

One component of a station equipment audit is the emissions analyzer gas audit. This audit is performed by independent auditors using bottled audit gases (independent of the station’s calibration gases), and the gas is introduced by the auditor at the tailpipe sampling probe rather than simply at the analyzer inlet (as in a 72-hour analyzer calibration). This type of audit adds an additional level of certainty about instrument measurement accuracy, since it can identify problems with the probe and the sample transport line from the probe to the I/M analyzer. If the analyzer fails the gas audit, it must be repaired (if necessary) and successfully re-calibrated before it may be used for additional I/M inspections involving tailpipe measurements.

Bottled gases containing zero gas and blends of HC, CO, NO_x, and CO_2 at low and mid-span concentration levels are used in a gas audit. The analyzer specification requires that the measured pollutant concentrations fall within 5.5% of the labeled (actual) bottle gas value for the low and mid-span level gases in order to pass the gas audit. The nominal bottle gas concentrations for the low and mid-span gas audits are listed in Table 3-19 (these are the same as the nominal bottle gas values for low- and mid-span calibrations). Actual labeled bottle gas concentrations may vary up to 5% from the nominal values, so the labeled bottle gas values are recorded in the analyzer and transmitted to the TIMS for each audit.

Table 3-19. Bottle Gas Concentrations for Low and Mid Span Audits

Gas	Low Span Nominal Concentration	Mid Span Nominal Concentration
HC (ppm)	200	3,200
CO (%)	0.5	8.0
NOx (ppm)	300	3,000
CO_2 (%)	6.0	12.0

The Texas SIP requires that each analyzer be audited at least twice per year. For the two-year dataset used for this analysis, this should result in an average of 4 audits per analyzer. A frequency distribution of the number of audits per analyzer is shown in Table 3-20. As can be seen from the table, a few of the 448 analyzers received many more than four audits. Many of the extra audits result from follow-up audits (re-audits) after an analyzer failed a portion of an initial audit. Also, more than half of the analyzers received fewer than 4 audits. It appears that the majority of the audits were occurring on an 8- or 9-month cycle, which would result in 2 or 3 audits per analyzer during the 24 month period under consideration. Since 25% of analyzers in the DFW/HGB programs received 8 or more audits during the same time period, it appears that the audits are performed less frequently in the Austin area.

Table 3-20. Number of Gas Audits per Analyzer Over a Two-Year Period

Number of Audits	Number of Analyzers	Percent of Analyzers
1	35	7.8%
2	88	19.6%
3	214	47.8%
4	85	19.0%
5	18	4.0%
6	5	1.1%
7	3	0.7%
Total	448	100.0%

The pass/fail results for the gas audit are based on whether or not the analyzer reads a pollutant concentration within 5.5% of the labeled bottle gas value:

$$\text{Difference (\%)} = 100 \times [(\text{Reading} - \text{Bottle Value}) / \text{Bottle Value}]$$

The distribution of percentage differences between readings and bottle gas values is shown in Figures 3-24 through 3-29 for CO, HC and CO_2 at the low- and mid-span levels. In almost all of the figures, the vast majority of readings fall between +/- 4% of the labeled gas values. The main exceptions were the low- and mid-span HC, with a somewhat wider spread.

Figure 3-24. Percent Difference Between Reading and Bottle Gas, Low-Span CO

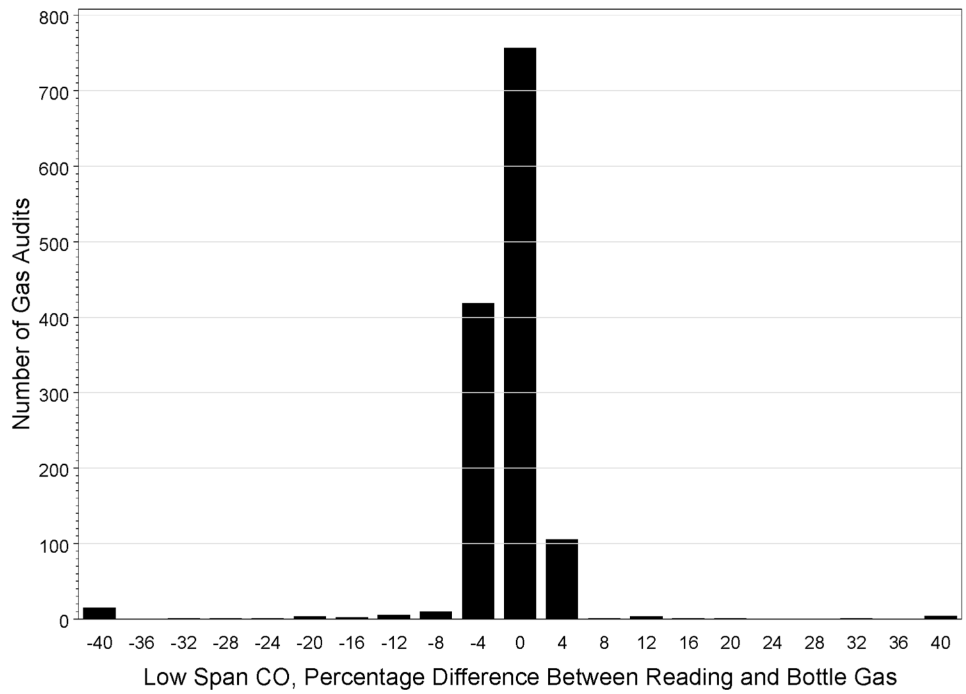


Figure 3-25. Percent Difference Between Reading and Bottle Gas, Low-Span HC

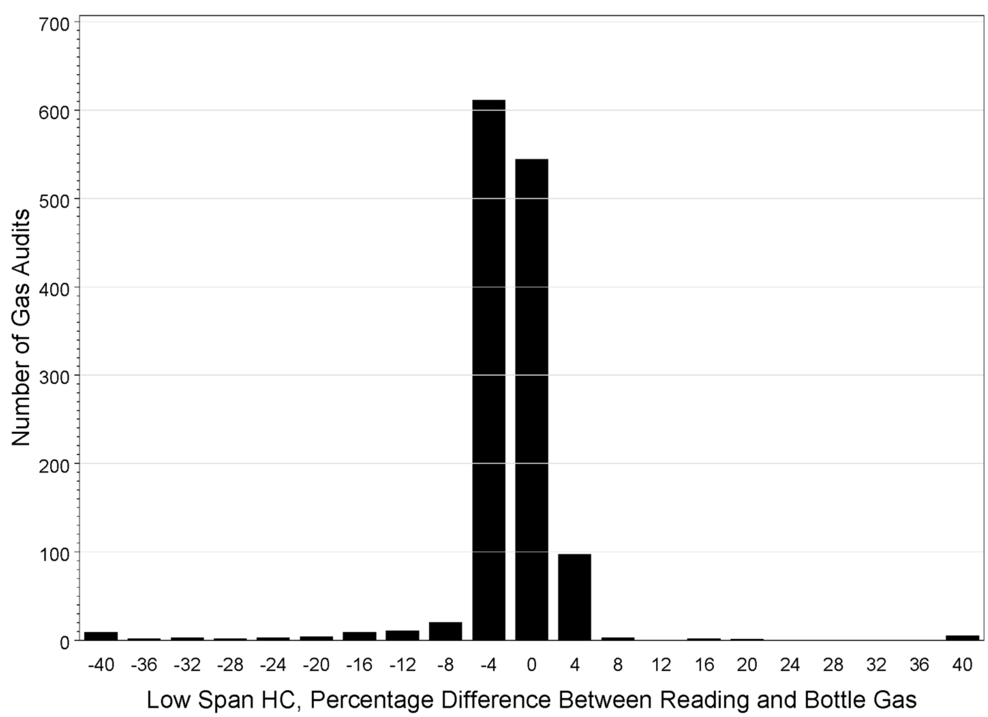


Figure 3-26. Percent Difference Between Reading and Bottle Gas, Low-Span CO_2

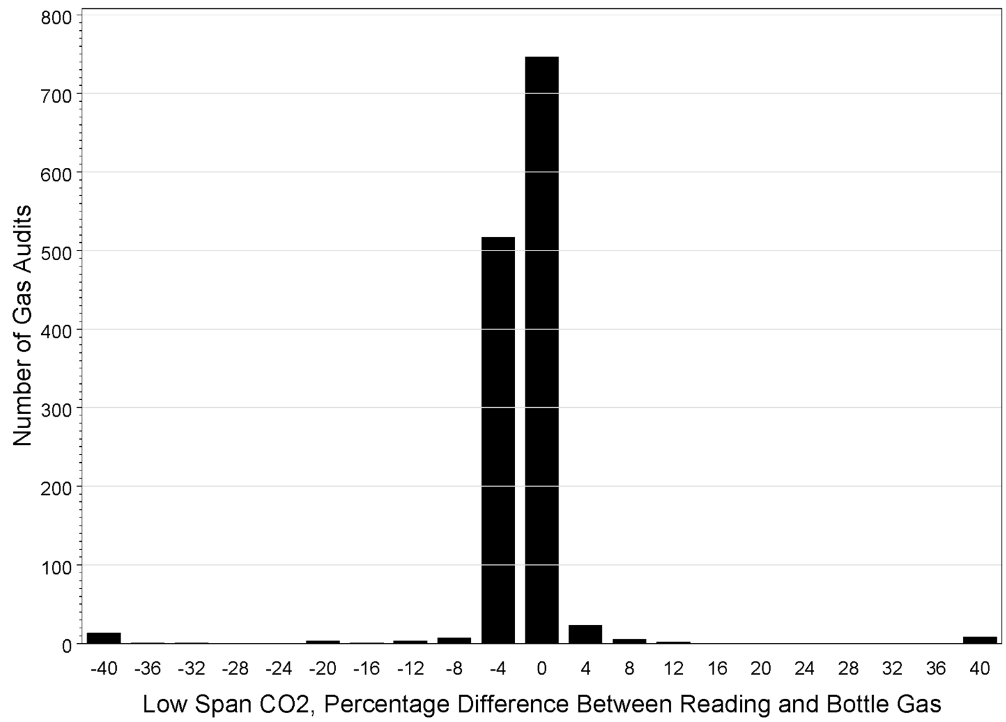


Figure 3-27. Percent Difference Between Reading and Bottle Gas, Mid-Span CO

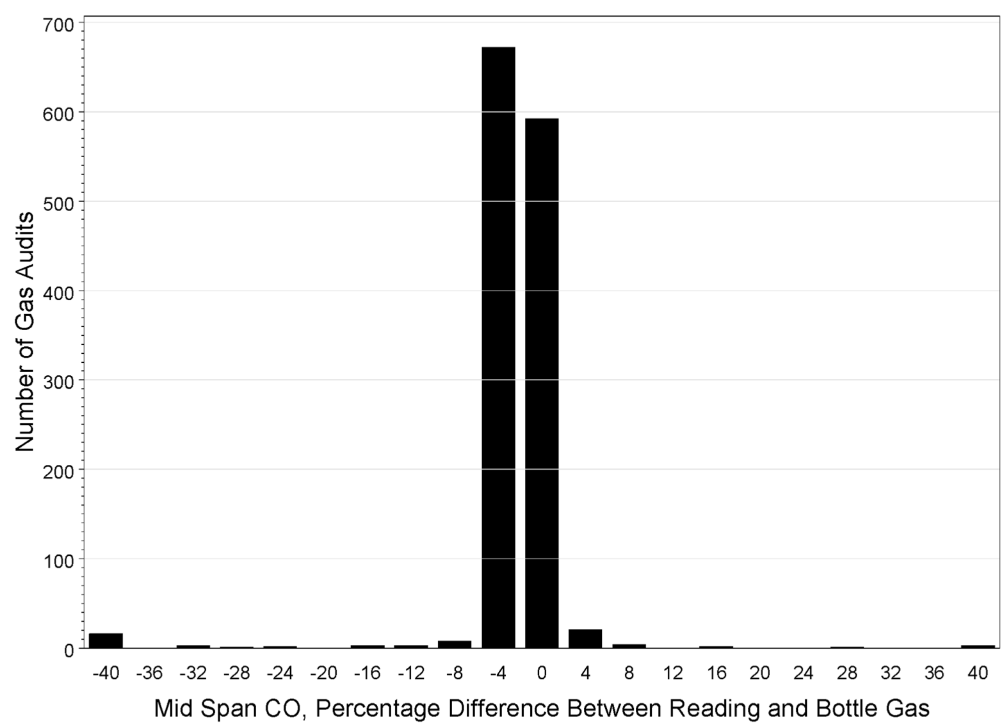


Figure 3-28. Percent Difference Between Reading and Bottle Gas, Mid-Span HC

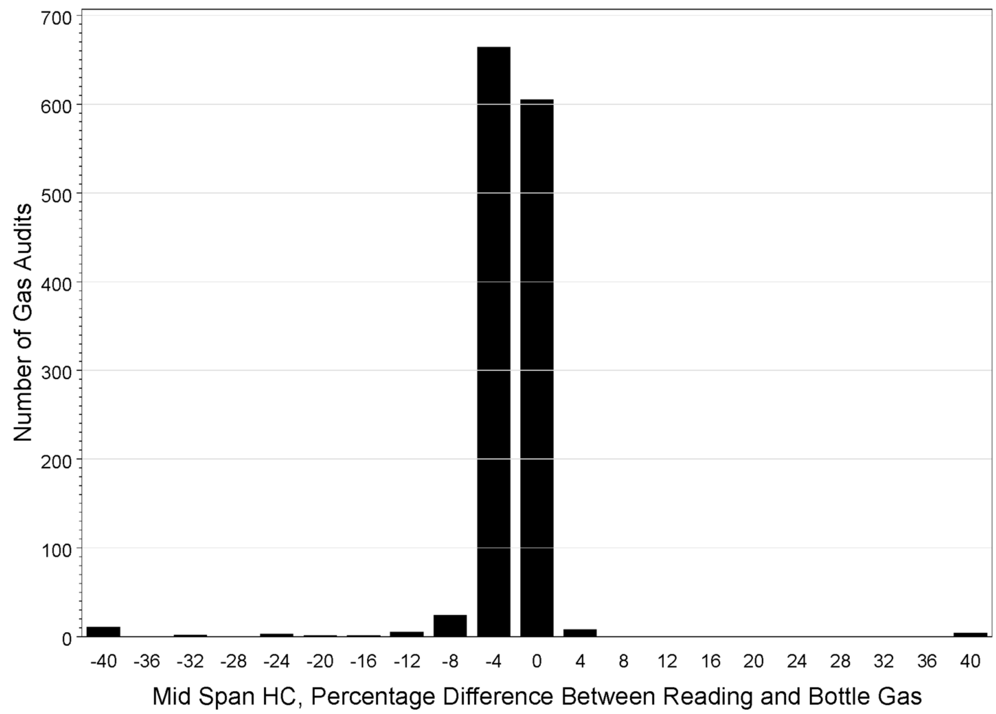


Figure 3-29. Percent Difference Between Reading and Bottle Gas, Mid-Span CO_2

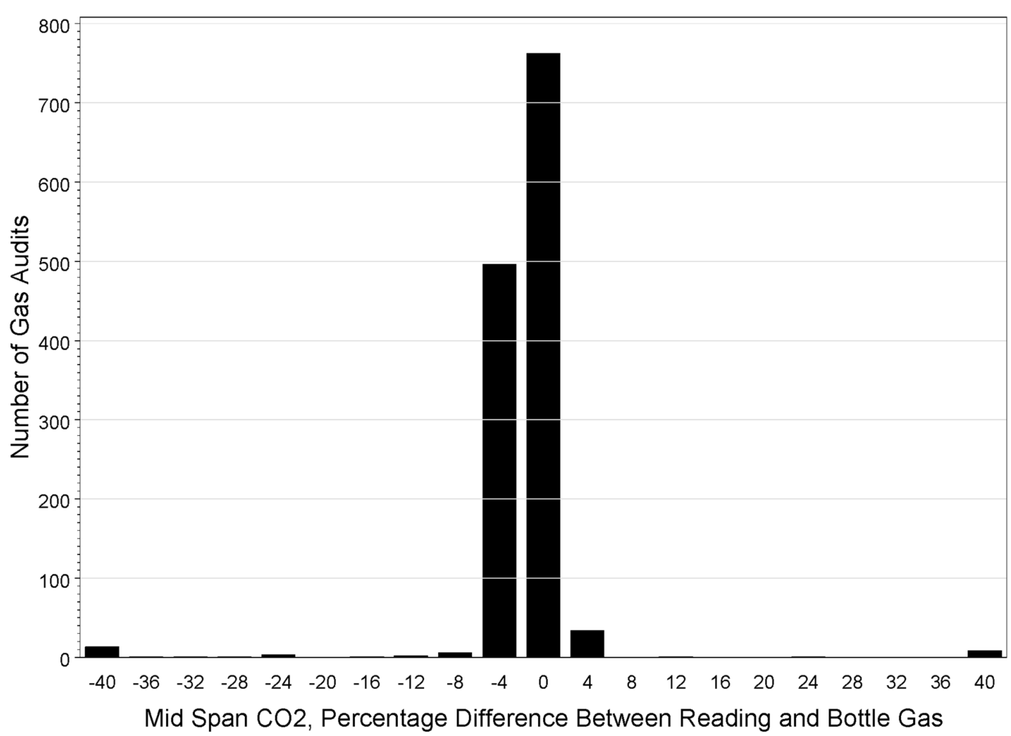


Table 3-21 shows pass/fail results for gas audits at the low- and mid- span levels. The table includes the pass/fail results that were recorded in the TIMS, as well pass/fail results calculated by ERG for this analysis (based on the labeled bottle gas value entered in the TIMS, the measured emissions concentration, and a 5.5% tolerance). It can be seen from Table 3-23 that the pass/fail results stored in the TIMS reconcile well with the pass/fail results ERG calculated from the measured span gas values. The largest discrepancies are 5 audits for which a failing result was calculated by ERG but a passing result was recorded in the TIMS. Almost all of those audits had one or more span gas measurements that were just slightly more than 5.5% different than the labeled bottle gas value, indicating that the discrepancy is probably caused by a slight difference in the rounding of results.

Table 3-21. Span Gas Pass/Fail Results from TIMS Compared to Calculated Results

Calculated Results	**TIMS Result**		
	Pass	**Fail**	**Total**
Pass	1218	0	1218
Fail	5	110	115
Entirely Missing	0	1	1
Total	1223	111	1334

The gas audit procedures specify that if an analyzer fails a gas audit, it must be locked out, repaired as necessary and calibrated in order to pass a re-audit. The calibration data described in the section above was combined with the audit gas data to determine whether the calibrations were actually taking place after the failed audits. In 35% of cases, an analyzer that failed an audit was calibrated or re-audited and passed within the next 24 hours, and another 25% of failing analyzers were calibrated or re-audited and passed within one week. The remaining 40% percent of failed audits took from one week up to three months to achieve a passing audit or successful calibration. It is possible that the audit found more serious problems with these analyzers, and they were taken off-line until an analyzer repair technician was able to undertake repairs on the analyzer. Compared to the rates for the DFW/HGB programs, it appears that the Austin analyzers that failed audits were not repaired as quickly – only 35% were repaired within 24 hours in Austin, whereas 51% were repaired within 24 hours in DFW/HGB.

3.4.4 Analyzer Lockouts

A Texas I/M gas analyzer or dynamometer is required to automatically lock itself out from performing I/M inspections if it is not successfully calibrated or verified on a regular basis. The calibration/verification requirements include:

1. Gas analyzers must be successfully calibrated and verified with BAR-97 calibration-blend gases at least every 72 hours, or they cannot be used for TSI inspections.
2. Gas analyzers must pass an internal leak check at least every 72 hours, or they cannot be used for TSI inspections.
3. Analyzers that fail a gas audit (as a component of an overt station audit) must be successfully calibrated and pass a re-audit before being used for TSI inspections. This requirement is evaluated in the previous section.

Calibration records, dynamometer coast-down check records, leak check records, and vehicle inspection records were used to determine whether analyzer and dynamometer calibrations and checks were taking place as required, and whether un-calibrated/un-checked analyzers or dynamometers were in fact locked out until passing a calibration.

The regularity of the two TSI-applicable types of 72-hour calibrations and checks (gas calibration and internal leak check) was investigated first. Each type of calibration/check was analyzed separately, since the different checks and calibrations were often performed at different times and recorded in separate records. It was not found to be meaningful to identify calibration/check lapses by simply calculating the time between passed calibrations and checks. The 72-hour deadline frequently fell on a Sunday, holiday, or other time that the station was not open, so the analyzer or dynamometer would legitimately remain un-calibrated/checked beyond 72 hours, until the station re-opened.

Instead, efforts were made to determine whether analyzers did lock themselves out from performing I/M inspections if more than 72 hours had passed since the previous successful calibration or check. To do this, the dataset of calibration and check records was added to the dataset of I/M inspection records. Only I/M inspection records for the Austin area in calendar years 2012 or 2013 were used, and only if the inspection involved a TSI inspection (safety-only inspections or OBD tests were excluded). Then, for each gas analyzer, any I/M inspections having date/times more than 72 hours after the most recent analyzer gas calibration or dynamometer check were identified. These inspections should not have been allowed by the analyzer software; the analyzer should have been locked out from performing vehicle inspections until it passed a calibration.

The results for each type of calibration or check are shown in Table 3-22. For each calibration or check, the number of I/M inspections taking place while the analyzer should have been locked out is listed. This result is also presented as a percentage of the total number of I/M inspections performed. It can be seen from the table that although the percentage of inspections performed by analyzers that were overdue for a calibration or check was small compared to the total inspections performed, a relatively large number of emissions inspections appear to have been performed at times when the analyzers should have been locked out. Notably, 0.4% of TSI inspections were performed at times that the analyzer should have been locked out. This is similar to the 0.5% reported for the DFW/HGB program areas.

Table 3-22. I/M Inspections More Than 72 Hours After Successful Calibration or Check

Calibration Type	I/M Inspections 72+ Hours After Passed Calibration or Check	I/M Inspections 72+ Hours After Passed Calibration Or Check (% of total inspections)	Total I/M Inspections
Span Gas Calibration	467	0.43%	108,661
Leak Check	198	0.18%	108,661

In order to determine why this was occurring, a review of the sequence of calibration/check records and vehicle inspection records for several different analyzers suggested that some analyzers that passed only one type of calibration or check (instead of all three) were still permitted to perform inspections. For example, passing a leak check would reset the 72-hour clock for each of the analyzer's gas calibration, leak check, and dynamometer coast-down check sequences, thereby allowing the analyzer to continue testing even though it had not passed a gas calibration or a dynamometer coast-down check in more than 72 hours.

The rate of inspections being performed while the analyzer should have been locked out was not the same for the different analyzer manufacturers, as shown in Table 3-23. The table shows that while both analyzer manufacturers had very low rates of performing inspections while they should have been locked out, the ESP analyzers had a slightly higher overall rate.

Table 3-23. I/M Inspections More Than 72 Hours After Successful Calibration or Check, by Analyzer Manufacturer

Analyzer ID	Inspections while not locked out		ASM & TSI Inspections while analyzer should be locked out		Total Inspections	
ESP	71,301	99.4%	421	0.6%	71,722	100.0%
WW	36,883	99.8%	56	0.2%	36,939	100.0%
Total for all analyzers	108,184	99.6%	477	0.4%	108,661	100.0%

3.5 OBD Inspection Analyzer Communication Performance

ERG analyzed Austin's TIMS OBD data to look for proper analyzer communication, as it is possible that certain models of analyzers cannot communicate with certain model year, make, and model vehicles. The objective of this task was to analyze TIMS data to determine if certain manufacturers of OBD inspection analyzers appear to have communication problems with certain makes, models, or model year vehicles, which would result in elevated fail to communicate rates for those vehicle groups.

For this task, ERG reviewed OBD inspection records to identify all tests with a result other than “P” in the “OBD2_DLC_RES” field of the test record. For these records, analysis was performed to identify the following:

- Rate of failure to communicate by analyzer manufacturer
- Rate of failure to communicate by vehicle make
- Rate of failure to communicate by vehicle model
- Rate of failure to communicate by vehicle model year

Results are presented for these four categories below.

3,477 of the 1,824,887 OBD test records (0.2%) had no information stored in the OBD communication result field. These records all had null values for ready result, fault code result, downloaded MIL status, and OBD pass/fail result. Two OBD test records had vehicle model years earlier than 1996 or later than 2014. 43,004 records were for heavy-duty (HD) vehicles or vehicles of unknown GVWR. All these records were excluded from the following results, leaving 1,778,404 OBD records in the dataset.

Communication Rates by Vehicle Model Year - Table 3-24 provides a summary of communication rates by model year of vehicles tested in the program.

The “MODEL_YEAR” field from the vehicle test result tables was used to determine model year. Values and percentages shown in the table are listed by model year. For example, 29,764 OBD tests were conducted on model year 1996 vehicles, and only 48 of these had an OBD fail to communicate status. Overall, very low numbers were seen for “failure to communicate” test results and the overall “failure to communicate” rates were near zero. The overall program-wide communication rate between vehicles and analyzers is 99.95%. This is similar to the 99.97% reported for the DFW/HGB program areas.

Table 3-24. OBD Communication Rates by Vehicle Model Year

Model Year	DLC is Damaged, Inaccessible, or Cannot be Found		Vehicle will not Communicate with Analyzer		Vehicle Successfully Communicates with Analyzer		Total Count of Tests by Model Yr
	Count	Percent	Count	Percent	Count	Percent	
1996	48	0.16%	0	0.0%	29,716	99.84%	29,764
1997	41	0.09%	0	0.0%	43,464	99.91%	43,505
1998	43	0.08%	0	0.0%	53,843	99.92%	53,886
1999	85	0.12%	0	0.0%	71,344	99.88%	71,429
2000	88	0.10%	0	0.0%	91,075	99.90%	91,163
2001	76	0.07%	0	0.0%	106,435	99.93%	106,511
2002	77	0.06%	0	0.0%	119,543	99.94%	119,620
2003	81	0.06%	0	0.0%	129,409	99.94%	129,490
2004	95	0.07%	0	0.0%	136,555	99.93%	136,650
2005	62	0.04%	0	0.0%	145,517	99.96%	145,579
2006	61	0.04%	0	0.0%	155,099	99.96%	155,160
2007	47	0.03%	0	0.0%	171,700	99.97%	171,747
2008	25	0.02%	0	0.0%	166,182	99.98%	166,207
2009	12	0.01%	0	0.0%	110,588	99.99%	110,600
2010	7	0.01%	0	0.0%	128,049	99.99%	128,056
2011	8	0.01%	0	0.0%	87,130	99.99%	87,138
2012	6	0.02%	0	0.0%	27,698	99.98%	27,704
2013	0	0.00%	0	0.0%	4,041	100.00%	4,041
2014	0	0.00%	0	0.0%	154	100.00%	154
Total	862	0.05%	0	0.0%	1,777,542	99.95%	1,778,404

Communication Rates by Equipment Manufacturer - Table 3-25 provides results of communication rates among the various analyzer manufacturers.

Again, the percentages shown for the "damaged, inaccessible or cannot be found," the "will not communicate" and the "successfully communicates" columns pertain to all tests conducted by each type of analyzer (not percentage of all tests). The two rightmost columns provide counts of tests and percentages of tests by each analyzer manufacturer relative to the total number of tests. The rate of communication problems was consistently low for each manufacturer.

Table 3-25. OBD Communication Rates by Equipment Manufacturer

Equipment Manufacturer (EM)	DLC is Damaged, Inaccessible, or Cannot be Found		Vehicle will not Communicate with Analyzer		Vehicle Successfully Communicates with Analyzer		Total Count of Tests by EM	% of Tests by EM
	Count	Percent	Count	Percent	Count	Percent		
ESP	763	0.06%	0	0.0%	1,234,791	99.94%	1,235,554	763
WW	99	0.02%	0	0.0%	542,751	99.98%	542,850	99
Total	862	0.05%	0	0.0%	1,777,542	99.95%	1,778,404	862

Communication Rates by Vehicle Make - To assess communication rates by vehicle make, vehicle registration records were merged with vehicle test records by VIN. The “VEHMK” field from the registration database was reviewed, but found to have numerous inconsistencies and errors. Similarly, the “MAKE” field from the vehicle test result table was evaluated and also found to have a number of inconsistencies. To obtain a consistent “make” list, VINs from the emission test records were decoded using the ERG VIN Decoder, and the “make” output from this decoding process was merged with the vehicle test records and used for this evaluation. Records for which a make from the VIN Decoder was unavailable were excluded from this analysis. Makes that were represented by 100 or fewer vehicles were also removed from the table, since sample sizes would be too small to provide meaningful results.

Table 3-26 provides a summary of communication rates among the various vehicle makes. The incident rates for “damaged, inaccessible, or cannot be found” or “no communication” were very low.

Table 3-26. OBD Communication Rates by Vehicle Make

Vehicle Make	DLC is Damaged, Inaccessible, or Cannot be Found		Vehicle will not Communicate with Analyzer		Vehicle Successfully Communicates with Analyzer		Total Count of Tests by Make	% of Overall Tests by Make
	Count	Percent	Count	Percent	Count	Percent		
ACURA	6	0.02%	-	0.00%	25,697	99.98%	25,703	1.45%
ASTON MARTIN	-	0.00%	-	0.00%	160	100.00%	160	0.01%
AUDI	6	0.06%	-	0.00%	9,976	99.94%	9,982	0.56%
BENTLEY	-	0.00%	-	0.00%	194	100.00%	194	0.01%
BMW	11	0.03%	-	0.00%	36,668	99.97%	36,679	2.07%
BUICK	19	0.08%	-	0.00%	22,738	99.92%	22,757	1.28%
CADILLAC	14	0.08%	-	0.00%	17,777	99.92%	17,791	1.00%
CHEVROLET	164	0.07%	-	0.00%	227,607	99.93%	227,771	12.85%
CHRYSLER	13	0.03%	-	0.00%	37,574	99.97%	37,587	2.12%
DAEWOO	1	0.60%	-	0.00%	165	99.40%	166	0.01%
DATSUN	3	0.02%	-	0.00%	12,269	99.98%	12,272	0.69%
DODGE	39	0.04%	-	0.00%	88,240	99.96%	88,279	4.98%
FERRARI	-	0.00%	-	0.00%	225	100.00%	225	0.01%
FORD	198	0.08%	-	0.00%	244,771	99.92%	244,969	13.82%
FORD/MAZDA	-	0.00%	-	0.00%	9,210	100.00%	9,210	0.52%
GMC	39	0.11%	-	0.00%	36,757	99.89%	36,796	2.08%
HONDA	42	0.02%	-	0.00%	180,598	99.98%	180,640	10.19%
HUMMER	1	0.05%	-	0.00%	1,911	99.95%	1,912	0.11%
HYUNDAI	15	0.04%	-	0.00%	42,152	99.96%	42,167	2.38%
INFINITI	3	0.02%	-	0.00%	17,663	99.98%	17,666	1.00%
ISUZU	7	0.16%	-	0.00%	4,466	99.84%	4,473	0.25%
JAGUAR	1	0.03%	-	0.00%	3,447	99.97%	3,448	0.19%
JEEP	20	0.05%	-	0.00%	42,085	99.95%	42,105	2.37%
KIA	7	0.02%	-	0.00%	33,711	99.98%	33,718	1.90%
LAND ROVER	2	0.04%	-	0.00%	4,639	99.96%	4,641	0.26%
LEXUS	2	0.00%	-	0.00%	47,064	100.00%	47,066	2.65%
LINCOLN	22	0.16%	-	0.00%	14,087	99.84%	14,109	0.80%
LOTUS	-	0.00%	-	0.00%	123	100.00%	123	0.01%
MASERATI	-	0.00%	-	0.00%	177	100.00%	177	0.01%
MAZDA	47	0.06%	-	0.00%	73,616	99.94%	73,663	4.15%
MERCEDES	6	0.02%	-	0.00%	28,497	99.98%	28,503	1.61%
MERCURY	4	0.03%	-	0.00%	15,057	99.97%	15,061	0.85%

Vehicle Make	DLC is Damaged, Inaccessible, or Cannot be Found		Vehicle will not Communicate with Analyzer		Vehicle Successfully Communicates with Analyzer		Total Count of Tests by Make	% of Overall Tests by Make
	Count	Percent	Count	Percent	Count	Percent		
MINI	-	0.00%	-	0.00%	6,306	100.00%	6,306	0.36%
MITSUBISHI	12	0.07%	-	0.00%	17,046	99.93%	17,058	0.96%
NISSAN	27	0.03%	-	0.00%	105,805	99.97%	105,832	5.97%
OLDSMOBILE	1	0.02%	-	0.00%	4,023	99.98%	4,024	0.23%
PLYMOUTH	2	0.11%	-	0.00%	1,802	99.89%	1,804	0.10%
PONTIAC	20	0.09%	-	0.00%	21,817	99.91%	21,837	1.23%
PORSCHE	2	0.04%	-	0.00%	4,546	99.96%	4,548	0.26%
SAAB	-	0.00%	-	0.00%	3,741	100.00%	3,741	0.21%
SATURN	34	0.21%	-	0.00%	16,147	99.79%	16,181	0.91%
SCION	-	0.00%	-	0.00%	9,978	100.00%	9,978	0.56%
SUBARU	3	0.02%	-	0.00%	17,346	99.98%	17,349	0.98%
SUZUKI	3	0.06%	-	0.00%	5,042	99.94%	5,045	0.28%
TOYOTA	30	0.01%	-	0.00%	229,243	99.99%	229,273	12.93%
VOLVO	5	0.03%	-	0.00%	18,581	99.97%	18,586	1.05%
VW	18	0.06%	-	0.00%	31,491	99.94%	31,509	1.78%
Total	849	0.05%	-	0.00%	1,772,235	99.95%	1,773,084	100.00%

Communication Rates by Vehicle Model - To assess communication rates by vehicle models, the following model designation fields were reviewed:

- The "MODEL" field from the vehicle test result tables was seen to have a number of inconsistencies and errors. This could be because it is a manual keyboard entry, but there may be other data entry methods for this field.

- veh_modl (derived from the merged registration records) was also seen to have a number of inconsistencies and errors.

- The "MODEL_CD" field from the emission test records was based on table lookup values and therefore appeared to be a more consistent descriptor for the vehicle's model designation. The Texas analyzer specification reports this "model code" is "The NCIC model code or acceptable TCEQ code, otherwise left blank." In order to correlate this "model code" to an actual vehicle model, all vehicle emission test record VINS were decoded using ERG's VIN Decoder, and the vehicle "series" (i.e., model) resulting from this decoding process was merged into the test record. An output table correlating "series" with "model code" was then developed using the most frequently occurring series associated with each model code.

Table 3-27 lists communication rates for each vehicle model code. The series that is shown in the table was derived from the decoded VIN as described above. Records for which model code was missing were excluded from the table. Records for the more uncommon series, i.e. less than 100 inspection records, were also excluded.

It can be seen from the table that no model codes/vehicle series had "damaged, inaccessible, or cannot be found" or "no communication" rates that were greater than 1 percent.

Table 3-27. OBD Communication Rates by Vehicle Model Code for Elevated Miscommunications

Model Code	Series (Model)	DLC is Damaged, Inaccessible, or Cannot be Found		Vehicle will not Communicate with Analyzer		Vehicle Successfully Communicates with Analyzer		Total Count of Tests by Model	% of Overall Tests by Model
		Count	Percent	Count	Percent	Count	Percent		
94	Ram Pickup 1500 2WD	0	0.00%	0	0.00%	10,354	100.00%	10,354	0.76%
133	F250 Super Duty 2WD	0	0.00%	0	0.00%	127	100.00%	127	0.01%
180	1500 2WD	0	0.00%	0	0.00%	246	100.00%	246	0.02%
200	Sentra / 200SX	0	0.00%	0	0.00%	476	100.00%	476	0.03%
230	SLK230	0	0.00%	0	0.00%	111	100.00%	111	0.01%
231	Truck Regular Bed	0	0.00%	0	0.00%	513	100.00%	513	0.04%
254	Grand Cherokee Laredo 2WD	2	0.04%	0	0.00%	5,190	99.96%	5,192	0.38%
300	ES300	3	0.03%	0	0.00%	11,126	99.97%	11,129	0.81%
400	LS400	0	0.00%	0	0.00%	845	100.00%	845	0.06%
500	528i	0	0.00%	0	0.00%	2,230	100.00%	2,230	0.16%
600	650i	0	0.00%	0	0.00%	177	100.00%	177	0.01%
626	626	6	0.17%	0	0.00%	3,425	99.83%	3,431	0.25%
700	740iL (Auto)	0	0.00%	0	0.00%	498	100.00%	498	0.04%
850	850	1	0.39%	0	0.00%	254	99.61%	255	0.02%
900	900SE / 900CSE	0	0.00%	0	0.00%	116	100.00%	116	0.01%
960	960	0	0.00%	0	0.00%	123	100.00%	123	0.01%
30C	CL	0	0.00%	0	0.00%	122	100.00%	122	0.01%
32T	TL	1	0.11%	0	0.00%	893	99.89%	894	0.07%
35R	RL	0	0.00%	0	0.00%	246	100.00%	246	0.02%
4RN	4Runner SR5	2	0.03%	0	0.00%	5,971	99.97%	5,973	0.44%
85F	850	0	0.00%	0	0.00%	130	100.00%	130	0.01%
AA4	A4/S4	3	0.12%	0	0.00%	2,503	99.88%	2,506	0.18%
AA6	A6/S6	0	0.00%	0	0.00%	402	100.00%	402	0.03%
AA8	A8	0	0.00%	0	0.00%	193	100.00%	193	0.01%
ACC	Accord EX	8	0.03%	0	0.00%	26,022	99.97%	26,030	1.91%
ALO	Alero Level II	0	0.00%	0	0.00%	1,598	100.00%	1,598	0.12%
ALT	Altima	4	0.02%	0	0.00%	23,997	99.98%	24,001	1.76%
ARL	RL	0	0.00%	0	0.00%	317	100.00%	317	0.02%

Model Code	Series (Model)	DLC is Damaged, Inaccessible, or Cannot be Found		Vehicle will not Communicate with Analyzer		Vehicle Successfully Communicates with Analyzer		Total Count of Tests by Model	% of Overall Tests by Model
		Count	Percent	Count	Percent	Count	Percent		
AS4	A4/S4	1	0.33%	0	0.00%	303	99.67%	304	0.02%
ASP	Aspen Limited 2WD	0	0.00%	0	0.00%	222	100.00%	222	0.02%
AST	Astro 2WD	0	0.00%	0	0.00%	733	100.00%	733	0.05%
ATL	TL	0	0.00%	0	0.00%	3,613	100.00%	3,613	0.26%
AUR	Aurora	1	0.41%	0	0.00%	244	99.59%	245	0.02%
AVA	Avalon	1	0.01%	0	0.00%	8,890	99.99%	8,891	0.65%
AVN	Avenger SE	1	0.11%	0	0.00%	923	99.89%	924	0.07%
BEE	New Beetle	0	0.00%	0	0.00%	1,341	100.00%	1,341	0.10%
BLZ	S10 Blazer 2WD	2	0.09%	0	0.00%	2,161	99.91%	2,163	0.16%
BON	Bonneville SE	0	0.00%	0	0.00%	705	100.00%	705	0.05%
BOX	986 Boxster	0	0.00%	0	0.00%	990	100.00%	990	0.07%
BRZ	Breeze	1	0.46%	0	0.00%	216	99.54%	217	0.02%
C15	C1500 Pickup 2WD	6	0.02%	0	0.00%	27,242	99.98%	27,248	2.00%
C23	C230	2	0.11%	0	0.00%	1,878	99.89%	1,880	0.14%
C25	C2500 Pickup 2WD	2	0.26%	0	0.00%	775	99.74%	777	0.06%
C28	C280	0	0.00%	0	0.00%	584	100.00%	584	0.04%
C35	C3500 Pickup 2WD	0	0.00%	0	0.00%	134	100.00%	134	0.01%
C70	C70	0	0.00%	0	0.00%	619	100.00%	619	0.05%
CAB	Cabrio Convertible	0	0.00%	0	0.00%	361	100.00%	361	0.03%
CAM	Camry	4	0.01%	0	0.00%	44,086	99.99%	44,090	3.23%
CAP	Caprice Classic	0	0.00%	0	0.00%	101	100.00%	101	0.01%
CAR	911	1	0.28%	0	0.00%	353	99.72%	354	0.03%
CAV	Cavalier	6	0.11%	0	0.00%	5,645	99.89%	5,651	0.41%
CEN	Century Custom	1	0.03%	0	0.00%	3,873	99.97%	3,874	0.28%
CHA	Charger (RWD)	1	0.02%	0	0.00%	4,486	99.98%	4,487	0.33%
CHL	Challenger R/T	0	0.00%	0	0.00%	399	100.00%	399	0.03%
CIR	Cirrus LXi	0	0.00%	0	0.00%	262	100.00%	262	0.02%
CIV	Civic LX	13	0.03%	0	0.00%	39,981	99.97%	39,994	2.93%
CL3	CLK320	0	0.00%	0	0.00%	184	100.00%	184	0.01%

Model Code	Series (Model)	DLC is Damaged, Inaccessible, or Cannot be Found		Vehicle will not Communicate with Analyzer		Vehicle Successfully Communicates with Analyzer		Total Count of Tests by Model	% of Overall Tests by Model
		Count	Percent	Count	Percent	Count	Percent		
CL4	CLK430	0	0.00%	0	0.00%	298	100.00%	298	0.02%
CNC	Concorde LX/LXi	1	0.13%	0	0.00%	743	99.87%	744	0.05%
CNT	Contour LX/SE	0	0.00%	0	0.00%	736	100.00%	736	0.05%
COA	Corolla/Matrix	10	0.03%	0	0.00%	29,250	99.97%	29,260	2.14%
CON	Continental	0	0.00%	0	0.00%	650	100.00%	650	0.05%
COU	Cougar	0	0.00%	0	0.00%	778	100.00%	778	0.06%
CRV	CR-V	1	0.01%	0	0.00%	6,683	99.99%	6,684	0.49%
CST	Celica	0	0.00%	0	0.00%	1,370	100.00%	1,370	0.10%
CUT	Cutlass GLS	0	0.00%	0	0.00%	228	100.00%	228	0.02%
CVC	Crown Victoria (Police)	6	0.09%	0	0.00%	6,629	99.91%	6,635	0.49%
CVN	Caravan C/V FWD	2	0.05%	0	0.00%	4,086	99.95%	4,088	0.30%
CVT	Corvette	0	0.00%	0	0.00%	3,465	100.00%	3,465	0.25%
DAK	Dakota 2WD	0	0.00%	0	0.00%	2,140	100.00%	2,140	0.16%
DEV	DeVille	0	0.00%	0	0.00%	3,077	100.00%	3,077	0.23%
DIA	Diamante LS	1	0.22%	0	0.00%	450	99.78%	451	0.03%
DIS	Discovery Series II; Class E	0	0.00%	0	0.00%	369	100.00%	369	0.03%
DUR	Durango SLT 2WD	1	0.04%	0	0.00%	2,369	99.96%	2,370	0.17%
E32	E320W	2	0.08%	0	0.00%	2,388	99.92%	2,390	0.18%
E42	E420	0	0.00%	0	0.00%	106	100.00%	106	0.01%
E43	E430W	0	0.00%	0	0.00%	175	100.00%	175	0.01%
E50	E500W	0	0.00%	0	0.00%	141	100.00%	141	0.01%
EC2	E250 2WD	0	0.00%	0	0.00%	189	100.00%	189	0.01%
ECH	Echo	0	0.00%	0	0.00%	882	100.00%	882	0.06%
ECL	Eclipse GS	4	0.12%	0	0.00%	3,291	99.88%	3,295	0.24%
ELD	Eldorado	0	0.00%	0	0.00%	235	100.00%	235	0.02%
ELN	Elantra (XD)	4	0.05%	0	0.00%	8,425	99.95%	8,429	0.62%
EPD	Expedition XLT 2WD	7	0.08%	0	0.00%	8,232	99.92%	8,239	0.60%
ESC	Escort SE	3	0.08%	0	0.00%	3,542	99.92%	3,545	0.26%

Model Code	Series (Model)	DLC is Damaged, Inaccessible, or Cannot be Found		Vehicle will not Communicate with Analyzer		Vehicle Successfully Communicates with Analyzer		Total Count of Tests by Model	% of Overall Tests by Model
		Count	Percent	Count	Percent	Count	Percent		
EST	Esteem	1	0.64%	0	0.00%	156	99.36%	157	0.01%
F15	F150 2WD	0	0.00%	0	0.00%	8,665	100.00%	8,665	0.63%
F25	F250 Super Cab	7	3.15%	0	0.00%	215	96.85%	222	0.02%
FBD	Firebird	1	0.11%	0	0.00%	947	99.89%	948	0.07%
FI1		0	0.00%	0	0.00%	286	100.00%	286	0.02%
FOC	Focus ZX4	1	0.02%	0	0.00%	6,228	99.98%	6,229	0.46%
FOR	Forester	0	0.00%	0	0.00%	931	100.00%	931	0.07%
FRT	Frontier	3	0.09%	0	0.00%	3,402	99.91%	3,405	0.25%
G20	G20	0	0.00%	0	0.00%	426	100.00%	426	0.03%
G35	G35	2	0.09%	0	0.00%	2,124	99.91%	2,126	0.16%
GAL	Galant ES / GTZ / LS	5	0.12%	0	0.00%	4,197	99.88%	4,202	0.31%
GCK	Grand Cherokee 2WD	0	0.00%	0	0.00%	563	100.00%	563	0.04%
GOL	Golf / GTI / Jetta Wagon	1	0.09%	0	0.00%	1,092	99.91%	1,093	0.08%
GRA	Grand Prix GT	10	0.26%	0	0.00%	3,854	99.74%	3,864	0.28%
GRM	Grand Am SE1	1	0.03%	0	0.00%	3,773	99.97%	3,774	0.28%
GS3	GS300-GS450	0	0.00%	0	0.00%	1,967	100.00%	1,967	0.14%
GS4	GS400	0	0.00%	0	0.00%	279	100.00%	279	0.02%
GTI	Jetta/Rabbit/GT I	0	0.00%	0	0.00%	1,414	100.00%	1,414	0.10%
GTO	G T O	0	0.00%	0	0.00%	308	100.00%	308	0.02%
GVT	Grand Vitara 2WD	0	0.00%	0	0.00%	423	100.00%	423	0.03%
I30	I30	0	0.00%	0	0.00%	1,311	100.00%	1,311	0.10%
IMP	Impala	2	0.01%	0	0.00%	15,537	99.99%	15,539	1.14%
INT	Integra	1	0.04%	0	0.00%	2,809	99.96%	2,810	0.21%
J30	J30	0	0.00%	0	0.00%	100	100.00%	100	0.01%
JET	Jetta	6	0.05%	0	0.00%	11,145	99.95%	11,151	0.82%
JMY	Jimmy 2WD	1	0.36%	0	0.00%	276	99.64%	277	0.02%
L47	LX470	0	0.00%	0	0.00%	288	100.00%	288	0.02%
LAN	Lancer ES	1	0.04%	0	0.00%	2,373	99.96%	2,374	0.17%
LCR	Land Cruiser	0	0.00%	0	0.00%	455	100.00%	455	0.03%

Model Code	Series (Model)	DLC is Damaged, Inaccessible, or Cannot be Found		Vehicle will not Communicate with Analyzer		Vehicle Successfully Communicates with Analyzer		Total Count of Tests by Model	% of Overall Tests by Model
		Count	Percent	Count	Percent	Count	Percent		
LEG	Legacy/Outback	1	0.04%	0	0.00%	2,415	99.96%	2,416	0.18%
LES	LeSabre Custom	0	0.00%	0	0.00%	2,190	100.00%	2,190	0.16%
LHS	LHS	0	0.00%	0	0.00%	244	100.00%	244	0.02%
LS6	LS	0	0.00%	0	0.00%	906	100.00%	906	0.07%
LUM	Lumina LS	0	0.00%	0	0.00%	1,336	100.00%	1,336	0.10%
M3	M3	0	0.00%	0	0.00%	965	100.00%	965	0.07%
M5	M5	0	0.00%	0	0.00%	267	100.00%	267	0.02%
M6		0	0.00%	0	0.00%	103	100.00%	103	0.01%
MAG	Magnum / Magnum SXT	0	0.00%	0	0.00%	713	100.00%	713	0.05%
MAL	Malibu LS	6	0.05%	0	0.00%	12,927	99.95%	12,933	0.95%
MAR	Grand Marquis LS	0	0.00%	0	0.00%	1,805	100.00%	1,805	0.13%
MAX	Maxima	2	0.02%	0	0.00%	10,676	99.98%	10,678	0.78%
MET	Geo Metro LSi	0	0.00%	0	0.00%	200	100.00%	200	0.01%
MGO	Montego Premier	0	0.00%	0	0.00%	370	100.00%	370	0.03%
MIA	MX-5 Miata	0	0.00%	0	0.00%	2,745	100.00%	2,745	0.20%
MIL	Millenia	0	0.00%	0	0.00%	662	100.00%	662	0.05%
MIR	Mirage ES	0	0.00%	0	0.00%	665	100.00%	665	0.05%
ML3	ML320	0	0.00%	0	0.00%	277	100.00%	277	0.02%
MOC	Monte Carlo LS	1	0.06%	0	0.00%	1,556	99.94%	1,557	0.11%
MON	Montero Sport 2WD	0	0.00%	0	0.00%	814	100.00%	814	0.06%
MPV	MPV	1	0.10%	0	0.00%	1,050	99.90%	1,051	0.08%
MR2	MR2 Spyder	0	0.00%	0	0.00%	266	100.00%	266	0.02%
MTA	Montana 2WD	0	0.00%	0	0.00%	228	100.00%	228	0.02%
MTN	Mountaineer 2WD	0	0.00%	0	0.00%	423	100.00%	423	0.03%
MUS	Mustang	2	0.01%	0	0.00%	15,457	99.99%	15,459	1.13%
MYS	Mystique GS	0	0.00%	0	0.00%	214	100.00%	214	0.02%
NAV	Navigator 2WD	5	0.17%	0	0.00%	2,941	99.83%	2,946	0.22%
NEO	Neon SXT	2	0.05%	0	0.00%	4,283	99.95%	4,285	0.31%
ODY	Odyssey	0	0.00%	0	0.00%	4,932	100.00%	4,932	0.36%
OTH		513	0.07%	0	0.00%	713,214	99.93%	713,727	52.26%

Model Code	Series (Model)	DLC is Damaged, Inaccessible, or Cannot be Found		Vehicle will not Communicate with Analyzer		Vehicle Successfully Communicates with Analyzer		Total Count of Tests by Model	% of Overall Tests by Model
		Count	Percent	Count	Percent	Count	Percent		
PAS	Passat	7	0.13%	0	0.00%	5,418	99.87%	5,425	0.40%
PAV	Park Avenue	1	0.17%	0	0.00%	579	99.83%	580	0.04%
PRE	Prelude	4	0.55%	0	0.00%	729	99.45%	733	0.05%
PRI	Prius	3	0.04%	0	0.00%	8,476	99.96%	8,479	0.62%
PRO	ProtGgG	12	0.17%	0	0.00%	6,864	99.83%	6,876	0.50%
PTH	Pathfinder	0	0.00%	0	0.00%	2,488	100.00%	2,488	0.18%
Q45	Q45	0	0.00%	0	0.00%	396	100.00%	396	0.03%
QST	Quest	0	0.00%	0	0.00%	818	100.00%	818	0.06%
QTO	A4/S4	1	0.13%	0	0.00%	771	99.87%	772	0.06%
QXA	QX4 (SUV)	0	0.00%	0	0.00%	274	100.00%	274	0.02%
RAB	Jetta/Rabbit/GT I	0	0.00%	0	0.00%	939	100.00%	939	0.07%
RAV	RAV4	0	0.00%	0	0.00%	3,199	100.00%	3,199	0.23%
REG	Regal LS	1	0.06%	0	0.00%	1,784	99.94%	1,785	0.13%
RIV	Riviera	0	0.00%	0	0.00%	101	100.00%	101	0.01%
RNG	Ranger 2WD	0	0.00%	0	0.00%	2,896	100.00%	2,896	0.21%
ROD	Rodeo 2WD	1	0.11%	0	0.00%	936	99.89%	937	0.07%
RRV	Range Rover HSE	1	0.11%	0	0.00%	930	99.89%	931	0.07%
RX3	RX300	0	0.00%	0	0.00%	1,136	100.00%	1,136	0.08%
S10	S10 Pickup 2WD	0	0.00%	0	0.00%	1,671	100.00%	1,671	0.12%
S20	S2000	0	0.00%	0	0.00%	670	100.00%	670	0.05%
S30	SC300	0	0.00%	0	0.00%	147	100.00%	147	0.01%
S40	S40 / V50	0	0.00%	0	0.00%	1,808	100.00%	1,808	0.13%
S70	S70 / V70	0	0.00%	0	0.00%	868	100.00%	868	0.06%
S80	S80	1	0.07%	0	0.00%	1,388	99.93%	1,389	0.10%
SAB	Sable GS	0	0.00%	0	0.00%	2,056	100.00%	2,056	0.15%
SAF	Safari 2WD	0	0.00%	0	0.00%	184	100.00%	184	0.01%
SC	SC2 / SL1 / SW1	5	0.52%	0	0.00%	957	99.48%	962	0.07%
SEB	Sebring LX	1	0.02%	0	0.00%	4,791	99.98%	4,792	0.35%
SEN	Sentra	6	0.05%	0	0.00%	11,227	99.95%	11,233	0.82%
SEP	Sephia/Spectra	0	0.00%	0	0.00%	334	100.00%	334	0.02%
SEV	SLS	0	0.00%	0	0.00%	533	100.00%	533	0.04%
SIL	Silhouette 2WD	0	0.00%	0	0.00%	115	100.00%	115	0.01%

Model Code	Series (Model)	DLC is Damaged, Inaccessible, or Cannot be Found		Vehicle will not Communicate with Analyzer		Vehicle Successfully Communicates with Analyzer		Total Count of Tests by Model	% of Overall Tests by Model
		Count	Percent	Count	Percent	Count	Percent		
SKY	Skylark	1	0.97%	0	0.00%	102	99.03%	103	0.01%
SL	SL2 / SW2	12	0.41%	0	0.00%	2,924	99.59%	2,936	0.21%
SL5	SL500R	0	0.00%	0	0.00%	426	100.00%	426	0.03%
SNA	Sienna LE	0	0.00%	0	0.00%	3,457	100.00%	3,457	0.25%
SNF	Sunfire	2	0.12%	0	0.00%	1,700	99.88%	1,702	0.12%
SON	Sonata	2	0.02%	0	0.00%	9,410	99.98%	9,412	0.69%
SPT	Legacy/Outback	1	0.04%	0	0.00%	2,238	99.96%	2,239	0.16%
STA	Stratus SXT	2	0.06%	0	0.00%	3,626	99.94%	3,628	0.27%
STS	STS	0	0.00%	0	0.00%	322	100.00%	322	0.02%
SUB	C1500 Suburban 2WD	0	0.00%	0	0.00%	2,170	100.00%	2,170	0.16%
SW	SL2 / SW2	2	1.13%	0	0.00%	175	98.87%	177	0.01%
T10	T100 XTRACAB 2WD	0	0.00%	0	0.00%	136	100.00%	136	0.01%
TAC	Tacoma Deluxe	0	0.00%	0	0.00%	5,815	100.00%	5,815	0.43%
TAH	Tahoe 2WD	1	0.01%	0	0.00%	9,425	99.99%	9,426	0.69%
TAU	Taurus SE	2	0.02%	0	0.00%	12,178	99.98%	12,180	0.89%
TC	Scion tC	0	0.00%	0	0.00%	1,151	100.00%	1,151	0.08%
TER	Tercel	0	0.00%	0	0.00%	334	100.00%	334	0.02%
THU	Thunderbird	2	0.22%	0	0.00%	905	99.78%	907	0.07%
TIB	Tiburon	1	0.08%	0	0.00%	1,255	99.92%	1,256	0.09%
TL	TL	0	0.00%	0	0.00%	1,139	100.00%	1,139	0.08%
TOW	Town Car Signature	12	0.16%	0	0.00%	7,377	99.84%	7,389	0.54%
TRA	Tracer LS	0	0.00%	0	0.00%	201	100.00%	201	0.01%
TRP	Trooper 4WD	1	0.29%	0	0.00%	343	99.71%	344	0.03%
TUN	Tundra SR5	0	0.00%	0	0.00%	5,253	100.00%	5,253	0.38%
V15	Ram Pickup 2WD	2	0.17%	0	0.00%	1,190	99.83%	1,192	0.09%
V40	S40 / V40	0	0.00%	0	0.00%	131	100.00%	131	0.01%
V70	V70	2	0.22%	0	0.00%	914	99.78%	916	0.07%
VAN	Vandenplas	0	0.00%	0	0.00%	157	100.00%	157	0.01%
VEN	Venture 2WD Extended Van	0	0.00%	0	0.00%	123	100.00%	123	0.01%

Model Code	Series (Model)	DLC is Damaged, Inaccessible, or Cannot be Found		Vehicle will not Communicate with Analyzer		Vehicle Successfully Communicates with Analyzer		Total Count of Tests by Model	% of Overall Tests by Model
		Count	Percent	Count	Percent	Count	Percent		
VGR	Villager Wagon	0	0.00%	0	0.00%	186	100.00%	186	0.01%
VIP	Viper SRT-10	0	0.00%	0	0.00%	124	100.00%	124	0.01%
VOY	Voyager	0	0.00%	0	0.00%	405	100.00%	405	0.03%
WIN	Windstar LX	0	0.00%	0	0.00%	1,007	100.00%	1,007	0.07%
WRG	Wrangler 4WD	3	0.07%	0	0.00%	4,121	99.93%	4,124	0.30%
XJ8	XJ	0	0.00%	0	0.00%	567	100.00%	567	0.04%
XJR	XJR	0	0.00%	0	0.00%	121	100.00%	121	0.01%
XK8	XK8	0	0.00%	0	0.00%	129	100.00%	129	0.01%
XPL	Explorer XL	0	0.00%	0	0.00%	5,665	100.00%	5,665	0.41%
XTE	Xterra	0	0.00%	0	0.00%	2,986	100.00%	2,986	0.22%
XXX	Wrangler 4WD	1	0.02%	0	0.00%	5,602	99.98%	5,603	0.41%
YUK	Yukon 2WD	1	0.04%	0	0.00%	2,666	99.96%	2,667	0.20%
Z3	Z3	1	0.26%	0	0.00%	377	99.74%	378	0.03%
	All Models	786	0.06%	-	0.00%	1,364,840	99.94%	1,365,626	100.00%

3.6 TIMS Handling of OBD Codes

ERG analyzed TIMS OBD data to evaluate the accuracy of OBD data collected in the program. This is a process-based measure for inspection effectiveness. The handling of OBD readiness, pending trouble codes and communication failures varies among I/M programs. The objective of this task was to analyze OBD inspection records to ensure OBD test results are appropriate for various OBD test dispositions, such as a vehicle with too many OBD monitors "not ready," a vehicle with "pending" diagnostic trouble codes (DTCs), or a vehicle with which the OBD analyzer cannot communicate.

Program Description and Results of Analysis

Proper handling of various OBD test scenarios is defined in Parts 85.2207 and 85.2222 of Title 40 of the Code of Federal Regulations and also in various OBD implementation guidance documents issued by the EPA. Appropriate responses to the various test scenarios are summarized here, and serve as the basis for analysis for this task. The dataset for this analysis included records for Austin area OBD inspections between 1 January 2012 and 31 December 2013. Records for inspections that were aborted were excluded from the dataset, as were records for which either the OBD result or the overall result was not "P" (pass) or "F" (fail). Because this analysis was performed with the goal of determining whether OBD inspection guidelines are enforced, only records for light-duty vehicles were used. Records for heavy-duty vehicles (>8500 lbs GVWR) for which the OBD test pass/fail results are not enforced and for vehicles with no GVWR given (because these might be heavy-duty vehicles) were also removed from the dataset, leaving 13,611,405 records in the dataset[4]. Finally, re-test inspections on OBD vehicles that included a safety or gas cap re-inspection, but did not include an OBD re-inspection (because the vehicle had passed OBD in a preceding inspection) were also excluded from the dataset, leaving 1,742,559 records in the dataset.

Diagnostic Link Connector Communication Status – According to federal guidelines, a diagnostic link connector (DLC) that is missing, tampered, or otherwise inoperable is a basis for failure, but the vehicle may be "rejected" for a DLC that is inaccessible or cannot be located. Failure to communicate with an OBD analyzer is also a basis for failure. To perform this analysis, the result stored in the "OBD2_DLC_RES" field was compared with that in the "OBD2_PF_FLAG" field. No test results with a "D" (damaged), "N" (connected but will not communicate), "L" (inspector cannot find DLC), or "I" (DLC is inaccessible) in the "OBD2_DLC_RES" should have a "P" in the "OBD2_PF_FLAG". Results of this analysis are shown in Table 3-28.

4 HD vehicles were identified using the tx96_type field equal to 1 and the tx96_gvw_actual field being greater than zero but less than 8,501.

Table 3-28. Comparison of DLC Communication Status with Overall OBD Test Results

DLC Communication Status	Overall OBD Test Results	
	Fail	Pass
"D" (damaged)	618	0
"I" (DLC is inaccessible)	136	0
"L" (inspector cannot find DLC)	82	0
Total count of "D", "I", "L", and "N" Tests	836	0
"P" (communication successful)	98,164	1,644,395
Total	99,000	1,644,395

As can be seen in the table, no test records have a DLC communication status of "D", "I", or "L" combined with an overall OBD result of "pass". The DLC fail to communicate was enforced on all OBD tests conducted on light-duty vehicles during the period of evaluation.

Because successful communication with the inspection analyzer is critical for all other OBD results, the OBD records with OBD2_DLC_RES results other than "P" were removed from the dataset for the other analyses that comprise the remainder of this section. This left 1,742,559 records in the dataset.

Agreement between OBD test result and overall test result – A vehicle that fails the OBD inspection should fail the overall inspection, excluding any test exceptions such as converting to a backup tailpipe test.

To determine if OBD failures are properly enforced, that is, reflected in the overall inspection disposition, a query was performed to quantify the number of vehicles that failed the OBD portion of the test ("F" in the "OBD2_PF_FL" field) but passed the overall OBD test ("P" in the "OVERALL_RESULTS" field). Table 3-29 shows that no tests were recorded with a "fail" in the OBD portion of the test but a "pass" for the overall test. All OBD inspections have agreement between the OBD result and the overall test result.

Table 3-29. Comparison of OBD Test Result with Overall Test Result

Result of OBD Test	Overall Test Result				Total	
	Fail		Pass			
Fail	98,164	100.0%	-	0.0%	98,164	5.6%
Pass	68,001	4.1%	1,576,394	95.9%	1,644,395	94.4%
Total	166,165	9.5%	1,576,394	90.5%	1,742,559	100.0%

Inspector-Entered Malfunction Indicator Light (MIL) bulb check - This is also referred to as the Key On / Engine Off (KOEO) check. The inspector turns the vehicle's ignition key to the "on" position, but does not start the vehicle, in order to illuminate the MIL. Results are manually entered into the analyzer (via keyboard) by the inspector. If the MIL does not illuminate, the vehicle should fail the OBD portion of the inspection.

To perform this analysis, the results for the inspector keyboard-entered MIL bulb check ("OBD2_MIL_CHECK" field of the test record) were compared with results of the overall OBD test result ("OBD2_PF_FLAG" field), to ensure that a MIL bulb check failure always results in an OBD test failure. The "OBD2_MIL_CHECK" results are "Y" or "K", which is a pass (yes, the MIL did illuminate or keyless ignition), and "N", which is a fail (no, the MIL did not illuminate). No records were found where a KOEO MIL result of "N" (fail) did not receive a failing OBD result. The results are presented in Table 3-30 below.

Table 3-30. Comparison of KOEO MIL Bulb Check Result with Overall OBD Test Result

Result of KOEO MIL Bulb Check	Overall OBD Test Result		Total
	Fail	Pass	
N (fail)	3,983	-	3,983
K (pass)	457	35,029	35,486
Y (pass)	93,724	1,609,366	1,703,090
Total	98,164	1,644,395	1,742,559

Inspector-Entered Engine-Running MIL Illumination Status – The key-on engine running result manually entered by the inspector is a basis for failure. No vehicle with an "F" in the "OBD2_MIL_ON_RUN" field should have a "P" in the "OBD2_PF_FLAG" field of the OBD test record. The "OBD2_MIL_ON_RUN" results are "Y", which is a pass (Y = MIL turned off after the vehicle was started) or "N", which is a fail (N = MIL stayed illuminated after the vehicle was started). Table 3-31 shows that the MIL Illumination Status appears to be enforced as a condition for OBD failure: no inspections were recorded with a MIL Illumination status of "N" and an overall OBD result of "P". However, since the Key On Engine Running MIL Illumination Status is manually entered by the inspector, accuracy of this entry is not automatically enforced by the analyzer.

Table 3-31. Comparison of Inspector-Entered MIL Illumination Status (Engine Running) with Overall OBD Test Result

Result of MIL Illumination Status	Overall OBD Test Result		Total
	Fail	Pass	
N (Fail)	15,242	-	15,242
Y (Pass)	82,922	1,644,395	1,727,317
Total	98,164	1,644,395	1,742,559

MIL commanded on – A vehicle with the MIL commanded on and with stored emissions-related DTCs should fail the OBD inspection, regardless of readiness status.

Manufacturer-specific (non-generic) DTCs are ignored in this pass/fail determination. To perform this analysis, all OBD test records were reviewed to determine the overall OBD pass/fail status in comparison with the downloaded MIL command status results. Specifically, any vehicle with "F" in the "OBD2_MIL_STATUS" should also have "F" in the "OBD2_PF_FLAG" field (if DTCs are present). Table 3-32 provides the results of this review.

Table 3-32. Comparison of Downloaded MIL Command Status with Overall OBD Test Result

Result of Downloaded MIL Status	Overall OBD Test Result				Total	
	Fail		Pass			
Fail	31,606	32.2%	2,401	0.1%	34,007	2.0%
Pass	66,558	67.8%	1,641,994	99.9%	1,708,552	98.0%
Total	98,164	100.0%	1,644,395	100.0%	1,742,559	100.0%

From Table 3-32, it can be seen that 2,401 test records (0.1% of all OBD "pass" test records) have a MIL commanded on status yet receive an overall OBD pass result. However, none of these tests show any stored DTCs, in which case it is appropriate to pass the test. In conclusion, the downloaded OBD MIL command status was enforced for all OBD tests conducted on light-duty vehicles (< 8500 lbs. GVWR) with stored DTCs during the period of evaluation.

Readiness Evaluation – Federal guidelines recommend two or fewer unset non-continuous monitors be allowed for 1996-2000 vehicles, and only one (or none) unset non-continuous monitors be allowed for 2001 and newer vehicles. Vehicles with higher counts of unset non-continuous monitors should not receive a pass result. They should be failed or rejected on the basis of the OBD system's readiness status. However, certain vehicles that are designated as "transitional vehicles" are permitted to receive a tailpipe inspection if they are found to be not ready based on non-continuous monitor status at the time of an OBD inspection. To prevent any confusion of the results, these vehicles were excluded from this analysis of readiness. 1,327 records with transitional vehicles were excluded, leaving 1,741,232 records in the dataset for this analysis.

To perform this analysis, the OBD readiness status of test records was compared on a model-year basis to evaluate conformance with the readiness guidelines. Vehicles of model years 1996-2000 with three or more "not ready" non-continuous monitors should have an OBD readiness failure ("F" in the "OBD2_READY_RES" field of the test record), and an OBD test result of fail ("F" in the "OBD2_PF_FLAG" field of the test record). Vehicles with two or fewer "not ready" non-continuous monitors should have an OBD readiness result of pass ("P" in the "OBD2_READY_RES" of the test record). 2001 and newer vehicles with two or more "not ready" non-continuous monitors should have an OBD readiness failure ("F" in the "OBD2_READY_RES" of the test record), and an OBD test record result of fail ("F" in the "OBD2_PF_FLAG" field of the test record), while 2001 and newer vehicles with one or fewer "not ready" non-continuous monitors should have an OBD readiness result of pass ("P" in the "OBD2_READY_RES" field of the test record).

Table 3-33 compares OBD readiness status with the number of unset monitors for all OBD tests. Only non-continuous and "enabled" monitors are presented in this comparison.

Table 3-33. Unset Monitors Vs. Test Readiness Status for Inspections

Count of Unset Non-Continuous Monitors	**Counts of Tests of Vehicles Model Year 1996 through 2000**		**Counts of Tests of Vehicles Model Year 2001 and newer**	
	OBD "Not Ready"	**OBD "Ready"**	**OBD "Not Ready"**	**OBD "Ready"**
0	3	194,133	18	1,276,801
1	-	47,305	-	123,553
2	-	28,181	23,379	1,887
3	8,742	-	14,188	-
4	5,665	-	9,603	-
5	3,359	-	4,054	-
6	131	-	230	-
Total Count	17,900	269,619	51,472	1,402,241

Results in Table 3-33 show that a small number of tests (a total of 21) appear to have received an OBD "not ready" status despite having no unset monitors. Also, 1,887 vehicles of model year 2001 or newer with two unset readiness monitors still received a readiness result of "pass". Almost all of these occurred during a short period between June and August of 2013. These were limited to inspections performed by two analyzer manufacturers, and were probably limited in duration as a result of having been fixed by software updates.

Readiness Evaluation - Comparison of readiness result with overall pass/fail result – The pass/fail disposition of the readiness result field of the test record was compared with the overall OBD test disposition to see of any vehicles with a "not ready" status (as determined automatically by the analyzer) received an overall OBD test result of "pass". To perform this analysis, the "OBD2_READY_RES" field was compared to the "OBD2_PF_FLAG" fields in the analyzer OBD test records. Note that certain vehicles that are designated as "transitional vehicles" are permitted to receive a tailpipe inspection if they are found to be not ready (based on non-continuous monitor status) at the time of an OBD inspection. To prevent any confusion of the results, these vehicles were excluded from this analysis of readiness. 1,327 records with transitional vehicles were excluded, leaving 1,741,232 records in the dataset for this analysis. The results are shown in Table 3-34.

Table 3-34. Comparison of Readiness Status Field with Overall OBD Test Result

Readiness Status Check	Overall OBD Test Result				Total	
	Fail		Pass			
Fail (Not Ready)	69,352	70.8%	20	0.0%	69,372	4.0%
Pass (Ready)	28,553	29.2%	1,643,307	100.0%	1,671,860	96.0%
Total	97,905	100.0%	1,643,327	100.0%	1,741,232	100.0%

As can be seen in Table 3-34, only 20 of the vehicles with a "not ready" status received an overall "pass" result for the OBD portion of the test. This indicates that the OBD readiness status (as determined by the analyzer and stored in the OBD2_READY_RES" field of the test record) was almost always enforced for OBD tests performed during the period of evaluation.

Overall, for this sub-section for Austin as compared to DFW/HGB, the Austin results tend to be a bit "cleaner" than the DFW/HGB results for most of these measures, showing fewer surprising or unusual combinations.

4.0 Repair

ERG used two years of Texas TIMS data to analyze repair activities in order to demonstrate the extent and effectiveness of repairs directed by the I/M program. This task will cover process-based measures for repair effectiveness.

4.1 Number and Types of Repairs

ERG performed analysis on the number and types of repairs for the two years of I/M data. The inspectors at I/M stations have an opportunity to enter vehicle repair information into the inspection analyzer prior to conducting an emissions retest. A simple count of the number of repairs entered and stored in the TIMS database and a distribution of the repair types suggests the I/M program is causing repairs to be performed. As for repairs reported for the TCEQ's Low Income and Repair Assistance, Retrofit, and Accelerated Vehicle Retirement Program (LIRAP), since the repairs reported are documented on paper and not electronically, LIRAP repairs are not included in this analysis but will be described generally.

In an effort to determine the number and types of repairs performed as a result of the Texas I/M program, two sets of data were analyzed: the Texas TIMS repair data collected as described above and detailed repair information collected from The Texas Department of Public Safety (DPS) Recognized Emissions Repair Facilities (RERF) program.

4.1.1.1 General I/M Repairs

The TIMS database, provided by the TCEQ for this analysis, contained a large number of repair entries, but relatively little detail on the nature of repairs performed. The five repair categories listed in the TIMS, along with the corresponding number of performed repairs, are presented in Table 4-1 by model year group.

Table 4-1. Repairs Listed in the TIMS

Repair Type	Model Year	Number of Repairs	% of Repair Type	% of Total
Fuel System	pre-1980	0	0.00	0.00
	1980-1989	57	0.94	0.20
	1990-1999	1,885	31.22	6.52
	post-2000	4,095	67.83	14.15
	Total	*6,037*	*100.00*	*20.87*
Ignition / Electrical system	pre-1980	0	0.00	0.00
	1980-1989	38	3.02	0.13
	1990-1999	544	43.28	1.88
	post-2000	675	53.70	2.33
	Total	*1,257*	*100.00*	*4.34*
Emissions system	pre-1980	0	0.00	0.00
	1980-1989	93	1.29	0.32
	1990-1999	2,550	35.47	8.81
	post-2000	4,546	63.24	15.71
	Total	*7,189*	*100.00*	*24.85*
Engine Mechanical	pre-1980	0	0.00	0.00
	1980-1989	3	0.78	0.01
	1990-1999	142	36.79	0.49
	post-2000	241	62.44	0.83
	Total	*386*	*100.00*	*1.33*
Miscellaneous	pre-1980	0	0.00	0.00
	1980-1989	91	0.65	0.31
	1990-1999	4,311	30.65	14.90
	post-2000	9,661	68.70	33.39
	Total	*14,063*	*100.00*	*48.61*
	Grand Total	*28,932*		*100.00*

RERF Repairs

Relative to the TIMS, the separate RERF dataset obtained from DPS contains more comprehensive information about the nature of repairs performed. However, repairs made at RERFs only make up a fraction of overall repairs made throughout the I/M areas statewide. Nonetheless, the distribution of repairs performed at RERFs serves to illustrate the wide variety of repairs undertaken as a result of the Texas I/M program. Table 4-2 shows counts of repairs reported by stations participating in the RERF program.

Table 4-2. Repairs Performed at RERF Stations

Repair Type	Defective, Not Repaired	Repaired	% Repaired	Total Vehicles with This Defect	Defect % of Total
AIS	0	0	0	0	0.00
Battery/Charging System	0	8	100.0	8	3.16
CAT	0	18	100.0	18	7.11
Camshaft	0	1	100.0	1	0.40
Cylinder Head	0	0	0	0	0.00
EGR	0	24	100.0	24	9.49
EVAP	0	31	100.0	31	12.25
Emissions System	0	2	100.0	2	0.79
Eng. Cooling	0	9	100.0	9	3.56
Engine Block	0	1	100.0	1	0.40
Engine Crankcase Oil	0	0	0	0	0.00
Engine Exhaust	0	1	100.0	1	0.40
Engine Mechanical	0	2	100.0	2	0.79
Final Drive Ratio	0	3	100.0	3	1.19
Fuel Filter	0	4	100.0	4	1.58
Fuel Pump	0	7	100.0	7	2.77
Fuel System	0	2	100.0	2	0.79
Ignition/Electrical System	0	0	0	0	0.00
Injectors	0	11	100.0	11	4.35
Miscellaneous	0	28	100.0	28	11.07
O2 Sensor	0	27	100.0	27	10.67
Other	0	0	0	0	0.00
PCM	0	8	100.0	8	3.16
PCV	0	19	100.0	19	7.51
Spark Plug Wires	0	4	100.0	4	1.58
Spark Plugs	0	14	100.0	14	5.53
Spark Timing	0	9	100.0	9	3.56
TAC	0	2	100.0	2	0.79
Thermostat	0	0	0	0	0.00
Throttle Body	0	7	100.0	7	2.77
Trans/Final Drive	0	3	100.0	3	1.19
Valves (Mechanical)	0	1	100.0	1	0.40
Valves (Oil Seals)	0	0	0	0	0.00
Vehicle Fluids	1	6	85.7	7	2.77
Grand Total	1	252	99.6	253	100.00

Drive a Clean Machine

Texas has put in place a program to financially assist low income individuals with replacing vehicles that fail emissions testing. It is called the AirCheckTexas Drive a Clean Machine (DACM) and it is for qualified owners of vehicles that have failed the emissions test or whose vehicles are gasoline powered and 10 years old or older. The program was originally created under the Low Income Vehicle Repair Assistance, Retrofit and Accelerated Retirement Program (LIRAP); however, the program is now known as DACM as the result of further legislative amendments passed in 2007.

The DACM program provides financial assistance toward repair or, retirement and replacements of vehicles. This program is a financial assistance program for qualified owners of vehicles that fail an emissions test or they own a gasoline-powered vehicle ten years old or older. To qualify for the DACM program, a vehicle owner's net family income cannot exceed 300% of the federal poverty level, which varies by family unit size. The vehicle must pass the safety portion of the DPS motor-vehicle safety and emissions inspection, and driven under its own power to the inspection station must have failed an emissions test, must be currently registered in and has been registered in a program county for at least 12 of the 15 months preceding the application for assistance.

The repair assistance provides a voucher worth up to $600 for emissions-related repairs or retrofits performed at a participating DPS RERF. The retirement and replacement assistance offers a $3,000 voucher towards the purchase of a vehicle, current model year or up to three model years old, $3,000 voucher for a truck, current model year or up to two model years old or $3,500 for a replacement vehicle of the current model year or the previous three model years if the vehicle is a hybrid vehicle, electric vehicle, natural gas vehicle, or is in a class or category of vehicles that has been certified to meet federal Tier 2, Bin 3 or cleaner Bin certification under 40 Code of Federal Regulations §86.1811-04, as published in the February 10, 2000, *Federal Register* (65 FR 6698).

The replacement vehicle must have an odometer reading of not more than 70,000 miles and a sales price of $35,000 or less, for a car, current model year or up to three model years old; a sales price of $35,000 or less, for a truck, current model year or up to two model years old; or a sales price of $45,000 or less for a hybrid vehicle, electric vehicle, natural gas vehicle or a vehicle certified to meet or exceed federal Tier 2, Bin 3 or cleaner certification of the current model year or up to three model years old and have a gross vehicle weight rating less than 10,000 pounds.

For the period covering December 1, 2011 through November 30, 2013, 252 vehicle repairs were done at RERF stations in the Austin area under the DACM program.

4.2 Emissions Changes Associated with Repair

One way to measure the effectiveness of the Texas I/M program is to assess emissions from vehicles both before and after repairs and to calculate the average emissions change produced by different repair types. Different types of repairs tend to produce characteristic changes in emissions.

In the discussion below, the average emissions and the emissions changes produced by repairs during the evaluation period in the Texas I/M program are presented.

4.2.1.1 Emissions Changes as a Result of Repair

The average emissions of all vehicles in the current 2014 I/M analysis that received repairs are shown in Table 4-3. Both TSI Curb Idle and High Idle test results are presented. Average emissions for both inspections prior to and following repair cycles are shown, along with the average change between the two. In the current analysis, the TSI Curb Idle emissions change for HC and CO, respectively, was -72% and -75%.

Tables 4-4 and 4-5 present the same types of emissions averages as those shown in Table 4-3, but they are stratified by inspection year and model year group, respectively. These tables show that when stratifying by either inspection year or model year, emissions of HC, CO, and NO_x all decrease with increasing year, for both the TSI Curb Idle and High Idle tests.

Table 4-6 presents the most common repair slates (groups of common types of repairs) in the TIMS data, as originally presented and discussed in Table 4-1 above. Average before and after repair emissions levels were calculated for each repair category to determine the emissions effects of different combinations of repair types.

As shown in Table 4-6 for the TSI Curb Idle mode, seven combinations of the five repair categories dominate the repair slates used in Texas.

Table 4-3. Average Emissions Before and After Repairs

TSI Mode	N	HC (ppm)				CO (%)			
		Before Repair	After Repair	Change		Before Repair	After Repair	Change	
				Conc.	(%)			Conc.	(%)
Curb Idle	23053	48	14	-35	-72%	0.17	0.04	-0.13	-75%
High Idle	23053	27	8	-19	-71%	0.15	0.05	-0.11	-70%

Table 4-4. Average Emissions Before and After Repairs by Inspection Year

Inspection Year	TSI Mode	N	HC (ppm)				CO (%)			
			Before Repair	After Repair	Change		Before Repair	After Repair	Change	
					Conc.	(%)			Conc.	(%)
2012	Curb Idle	11835	52	15	-38	-72%	0.19	0.05	-0.14	-75%
2013	Curb Idle	11217	45	12	-32	-72%	0.15	0.04	-0.11	-76%
2012	High Idle	11835	30	8	-22	-72%	0.17	0.05	-0.12	-72%
2013	High Idle	11217	24	7	-17	-71%	0.13	0.04	-0.09	-69%

Table 4-5. Average Emissions Before and After Repairs by Model Year Group

Model Year	TSI Mode	N	HC (ppm)				CO (%)			
			Before Repair	After Repair	Change		Before Repair	After Repair	Change	
					Conc.	(%)			Conc.	(%)
1980-1989	Curb Idle	166	599	172	-427	-71%	2.38	0.62	-1.76	-74%
1990-1999	Curb Idle	7138	143	40	-103	-72%	0.49	0.12	-0.37	-75%
post-2000	Curb Idle	15749	0	0	0	0	0.00	0.00	0.00	0
1980-1989	High Idle	166	394	82	-312	-79%	2.12	0.53	-1.59	-75%
1990-1999	High Idle	7138	78	23	-55	-71%	0.45	0.14	-0.31	-70%
post-2000	High Idle	15749	0	0	0	0	0.00	0.00	0.00	#0

Table 4-6. Average Emissions Before and After Repairs by Repair Category and Model Year Group

Repair Category	Model Year	TSI Mode	N	HC (ppm) Before Repair	HC (ppm) After Repair	HC Change Conc.	HC Change (%)	CO (%) Before Repair	CO (%) After Repair	CO Change Conc.	CO Change (%)
Miscellaneous	1980-1989	Curb Idle	46	511	179	-332	-65%	2.44	0.73	-1.72	-70%
Engine Mechanical	1980-1989	Curb Idle	2	178	56	-122	-68%	1.48	0.00	-1.48	-100%
Emissions System	1980-1989	Curb Idle	49	547	195	-352	-64%	2.06	0.75	-1.31	-64%
Emissions System & Misc	1980-1989	Curb Idle	1	279	272	-7	-3%	0.71	0.57	-0.14	-20%
Ignition/Electrical System	1980-1989	Curb Idle	25	669	192	-477	-71%	2.18	0.68	-1.50	-69%
Fuel System	1980-1989	Curb Idle	31	728	141	-587	-81%	2.69	0.44	-2.25	-84%
Fuel System & Emissions System	1980-1989	Curb Idle	5	786	149	-637	-81%	2.06	0.13	-1.93	-94%
Miscellaneous	1990-1999	Curb Idle	3033	122	32	-90	-74%	0.41	0.11	-0.29	-72%
Engine Mechanical	1990-1999	Curb Idle	91	89	31	-59	-66%	0.31	0.15	-0.16	-50%
Emissions System	1990-1999	Curb Idle	1916	164	47	-118	-72%	0.56	0.13	-0.43	-77%
Emissions System & Misc	1990-1999	Curb Idle	120	187	59	-128	-69%	0.80	0.15	-0.65	-82%
Ignition/Electrical System	1990-1999	Curb Idle	424	235	70	-165	-70%	0.82	0.20	-0.62	-75%
Fuel System	1990-1999	Curb Idle	1338	110	30	-79	-72%	0.41	0.08	-0.33	-80%
Fuel System & Emissions System	1990-1999	Curb Idle	51	290	108	-182	-63%	0.96	0.27	-0.69	-72%
Miscellaneous	post-2000	Curb Idle	7608	0.000	0	0.00	0	0.00	0.00	0.00	0
Engine Mechanical	post-2000	Curb Idle	180	0.000	0	0.00	0	0.00	0.00	0.00	0
Emissions System	post-2000	Curb Idle	3749	0.000	0	0.00	0	0.00	0.00	0.00	0
Emissions System & Misc	post-2000	Curb Idle	117	0.000	0	0.00	0	0.00	0.00	0.00	0
Ignition/Electrical System	post-2000	Curb Idle	545	0.000	0	0.00	0	0.00	0.00	0.00	0
Fuel System	post-2000	Curb Idle	3242	0.000	0	0.00	0	0.00	0.00	0.00	0
Fuel System & Emissions System	post-2000	Curb Idle	95	0	0	0.00	0	0.00	0.00	0.00	0
Miscellaneous	1980-1989	High Idle	46	348	104	-244	-70%	2.06	0.69	-1.37	-66%
Engine Mechanical	1980-1989	High Idle	2	211	60	-151	-72%	2.39	0.01	-2.38	-100%
Emissions System	1980-1989	High Idle	49	402	77	-325	-81%	2.06	0.60	-1.46	-71%
Emissions System & Misc	1980-1989	High Idle	1	142	92	-50	-35%	0.63	0.57	-0.06	-10%
Ignition/Electrical System	1980-1989	High Idle	25	388	69	-319	-82%	2.00	0.57	-1.43	-71%
Fuel System	1980-1989	High Idle	31	477	77	-400	-84%	2.40	0.31	-2.09	-87%
Fuel System & Emissions System	1980-1989	High Idle	5	546	65	-481	-88%	1.93	0.21	-1.72	-89%
Miscellaneous	1990-1999	High Idle	3033	64	18	-46	-72%	0.37	0.12	-0.25	-67%
Engine Mechanical	1990-1999	High Idle	91	65	18	-47	-72%	0.38	0.15	-0.23	-61%

Repair Category	Model Year	TSI Mode	N	HC (ppm) Before Repair	HC (ppm) After Repair	HC (ppm) Change Conc.	HC (ppm) Change (%)	CO (%) Before Repair	CO (%) After Repair	CO (%) Change Conc.	CO (%) Change (%)
Emissions System	1990-1999	High Idle	1916	93	28	-65	-70%	0.53	0.15	-0.38	-73%
Emissions System & Misc	1990-1999	High Idle	120	81	32	-48	-60%	0.66	0.16	-0.50	-76%
Ignition/Electrical System	1990-1999	High Idle	424	141	39	-101	-72%	0.76	0.23	-0.53	-70%
Fuel System	1990-1999	High Idle	1338	60	16	-45	-74%	0.34	0.09	-0.25	-72%
Fuel System & Emissions System	1990-1999	High Idle	51	157	95	-62	-40%	1.01	0.28	-0.72	-72%
Miscellaneous	post-2000	High Idle	7608	0	0	0	0	0.00	0.00	0.00	0
Engine Mechanical	post-2000	High Idle	180	0	0	0	0	0.00	0.00	0.00	0
Emissions System	post-2000	High Idle	3749	0	0	0	0	0.00	0.00	0.00	0
Emissions System & Misc	post-2000	High Idle	117	0	0	0	0	0.00	0.00	0.00	0
Ignition/Electrical System	post-2000	High Idle	545	0	0	0	0	0.00	0.00	0.00	0
Fuel System	post-2000	High Idle	3242	0	0	0	0	0.00	0.00	0.00	0
Fuel System & Emissions System	post-2000	High Idle	95	0	0	0	0	0.00	0.00	0.00	0

4.2.1.2 Issues with the Repair Data in the TIMS and RERF Datasets

There are several issues with the repair data contained in both the TIMS and RERF datasets that make analysis difficult. Future changes in the way data is collected and stored may alleviate many of these issues. These issues are described below and are very similar to those listed in previous reports.

TIMS Dataset – The repair data in the TIMS is entered by the inspector performing the inspection; however, the motorist often does not bring the vehicle repair form for the reinspection and this leads to the inspector leaving this information blank. Usually, most repair entries in the TIMS are made by inspectors that either work in the same facility where the reinspection takes place or made the repairs themselves.

The TIMS repair data includes only five different repair types, and these types are too general to permit a detailed analysis of the data. These types include fuel system, ignition/electrical system, emissions system, engine mechanical, and miscellaneous. As listed in Table 4-1, "miscellaneous" repairs make up almost 40% of the reported repairs. The addition of more detailed repair types during the collection of data would allow for more specificity in analysis. Previously, the Texas I/M program did have a more detailed list of repair types. However, because the TCEQ believed that a large fraction of inspectors did not fill out the repair list correctly, the TCEQ adopted the simpler list which was used during this evaluation period. Accuracy and completeness of repair data is a common issue in I/M programs which attempt to collect repair data.

It is recommended that Texas consider increasing the number of repair categories in the analyzer software, and eliminating the "Miscellaneous" category since that does not provide any useful information. The repair choices that inspectors see and choose from should be only those that apply to the technology of the vehicle being inspected.

Another problem, described in the costs section below, exists in the reported values of repair costs. A large number of repairs with a cost of $0 exists in the dataset, along with some extremely high (greater than $2,000) costs as well. The source of these errors is not clear, but the erroneous costs make it difficult to comprehensively assess costs across the entire dataset.

RERF Dataset – The RERF data is obtained by the DPS from the repair shops using a repair summary sheet form that is different than the vehicle repair form a motorist gets when their vehicle fails an inspection. DPS often receives these forms via fax. Once received by DPS, this information is entered into the RERF database and is used to calculate repair effectiveness ratings for each facility in the program.

The RERF dataset, while very specific with respect to the type of repair performed, lacks cost information for each individual repair performed. Repair costs are only reported as a total of all repairs performed each time a particular vehicle reports to a RERF.

It should also be noted that while the RERF dataset contains extensive vehicle, facility, and cost information, no emissions data from I/M testing is available in it.

4.3 Overall Success of Repairs to Vehicles Failing OBD

The objective of this task was to determine whether vehicles failing the OBD inspection are being properly repaired. ERG performed an analysis of the TIMS data for OBD failures and the presence of an illuminated MIL and diagnostic trouble codes followed by a OBD pass (MIL commanded off and no DTCs) as an indicator that the I/M program is resulting in OBD repairs. In this analysis, it is assumed that an OBD fail result followed by an OBD pass result is due to vehicle repairs, although it's possible that some of the OBD fails followed by an OBD pass could result from intermittent problems, self-correcting problems (such as a loose gas cap that's tightened on a vehicle refuel) or an OBD problem that is masked by unset readiness monitors (i.e., through a battery disconnect) on a subsequent passing retest. This "masking" issue is analyzed in Section 4.4 of this report. This analysis is analogous to the tailpipe emissions changes observed with repairs in Section 4.2.

Since OBD test pass/fail results are not enforced on heavy-duty vehicles (vehicles over 8500 lbs GVWR), Class 2 vehicles were excluded from this analysis. This left a dataset of 1,776,229 OBD inspection records available for the analysis.

Analysis and Results

For this task, ERG analyzed vehicle inspection records to identify tests with OBD failures, and then determine how many of those failures were subsequently corrected. To exclude initial test failures associated with readiness, test failures due to OBD/analyzer communication problems, and OBD tests failures converted to ASM tests, very specific definitions of OBD "fail" and "pass" were created. An OBD test failure was defined to be any test record with one or more stored DTCs, coinciding with the OBD MIL command status of "on," an OBD test disposition of "fail," and an overall test disposition of "fail." A passing result for an OBD test was defined as a downloaded OBD MIL commanded status of "off" and an OBD test disposition of "pass". These definitions were needed in order to fully control the analysis of MIL status, but they did leave some inspections that did not qualify as either a full "fail" or a full "pass" (i.e., OBD test was passed but overall I/M test was failed, etc). These tests for which the OBD test was passed but the overall I/M test was failed were excluded from this analysis.

Next, all individual vehicle I/M cycles that contained at least one failed OBD test were identified. I/M cycles were defined to be a single test, or a series of tests, performed on a vehicle until the vehicle passed the overall inspection and received a certificate or until the vehicle received a waiver and a certificate (or until December 31, 2013, the end of the evaluation period). Thus, if a vehicle failed the initial OBD test, the I/M cycle for that vehicle would be the initial failure, and any and all subsequent tests, until the vehicle passed its inspection and received a certificate, until a waiver and certificate were granted, or until the end of the evaluation period. Once the vehicle was issued a certificate, its next test (most likely for the following year's I/M inspection) would be a new I/M cycle. Any I/M cycles that began on or after October 1, 2013, were excluded from the analysis, since it would be possible that cycles starting so near the end of the date range of the dataset could have included additional re-inspections after December 31, 2013, and there would be no information for those inspections. Using these criteria, the dataset contained 1,430,878 I/M cycles that started before October 1, 2013.

After grouping by I/M cycle for vehicles with OBD failures (as previously defined), 24,000 I/M cycles were seen to include at least one failed OBD test. Of these cycles, 17,443 (71.4%) had a final OBD test disposition of "pass," which for purposes of this analysis was defined as a test with a downloaded MIL status of "pass" (MIL commanded off) and an OBD test disposition of "pass." The remaining vehicles never passed a subsequent OBD test; for these vehicles it was learned that 6,161 of them received the initial failing result but did not ever report for a re-inspection. Additional re-inspections may have occurred after December 31 2013, which would increase the overall "repaired" numbers. Additionally, 186 of these vehicles received waivers.

The Austin OBD final inspection pass rate of 71.4% is actually quite a bit lower than the pass rate seen for the HGB/DFW programs, of 85.4%. However, these overall percentages do not take into account any differences among the fleets, such as vehicle age distribution, that might affect the repair-then-pass rates.

4.4 Success of Repairs to Specific Emission Control Systems Failing OBD

For this analysis, diagnostic trouble codes were categorized based on the type of system they monitored, and using this categorization, ERG performed an analysis of repairs based on component categories, in order to determine if the program was resulting in effective emission control system repairs.

Analysis was performed on vehicles with DTC failures associated with oxygen sensors, exhaust gas recirculation systems, secondary air injection systems, catalyst efficiency, and evaporative emissions control system components.

Analysis and Results

This task was performed as a continuation of the analysis in Section 4.3. It uses combinations of vehicles and I/M cycles defined in that section. However, for this task, failure modes were assigned based on the diagnostic trouble codes (DTCs) contained in the failed test records. In addition to analysis of test records with evaporative system failures, analyses were also performed to identify and quantify repairs for the following types of OBD failures listed below. A list of DTCs that were included in each of these groups is given in Appendix A.

- Codes pertaining to insufficient oxygen sensor (O2 sensor) performance
- Codes pertaining to exhaust gas recirculation (EGR system) malfunctions
- Codes pertaining to secondary air injection system (AI system) malfunctions
- Codes pertaining to insufficient catalytic converter (catalyst) performance

These four additional categories of codes were included with this analysis because the "readiness status" of these systems, as well as the evaporative system, are specifically monitored by non-continuous monitors, and therefore the extent to which malfunctions may be masked by unset readiness monitors during a retest (which could result in a false pass) can be quantified. In this analysis, the extent of this potential masking is quantified along with the overall repair rates (as indicated by a fail test followed by a pass test).

For each of the failure categories, a failed inspection is defined as any inspection that contains at least one test record with stored DTCs, a downloaded OBD MIL commanded status of "on," an OBD test disposition of "fail," and an overall test disposition of "fail." Passed inspections were those which had a final test in that I/M cycle with a downloaded MIL status of "pass" (not commanded on) and an OBD test disposition of "pass."

To quantify the upper limit to which readiness may be masking unrepaired malfunctions during OBD retests, the following distinctions of "repaired" vehicles were made:

Total Repaired – This is the count of all vehicles that had at least one fail test with the final test classified as repaired. No regard is given to which (if any) monitors remain unset.

Repaired with Unset Monitors – This is the count of all "repaired" vehicles that have an unset monitor that may be masking the failure mode seen in the initial fail test.

For example, if a vehicle fails for an evaporative system malfunction, then the evaporative system monitor is unset on the final "pass" test for this vehicle, thereby possibly masking an unrepaired evaporative system malfunction. Once this monitor becomes "ready", any unrepaired malfunction would result in a stored evaporative system DTC and MIL re-illumination.

Confirmed Repaired – These are the vehicles whose monitors for which the initial failure occurred are "ready" in the final test, indicating that specific type of failure is not being masked by a "not-ready" monitor. Therefore, there is much higher confidence that these "confirmed repaired" vehicles are indeed properly repaired.

During this analysis of readiness status, some vehicles that failed for a certain system (e.g., EGR) were found to have a "not monitored" status for that monitored system (e.g., EGR not monitored). This is likely due to erroneous readiness status retrieved from certain vehicles and stored in that vehicle's test record. Since by definition this is impossible (a system with a stored code must be monitored), this subset of results was classified as "ready."

With regard to criteria used for categorizing "pass" and "fail" tests, it should also be noted that pending DTCs (also referred to as "soft" DTCs) are trouble codes that are insufficient for illuminating the MIL, generally because the number of successive repeat failures necessary for MIL illumination has not occurred. In accordance with the EPA guidance, vehicles are not failed for pending DTCs (stored DTCs but no MIL illumination) in the Texas program. Results from this repair analysis follows that strategy, and therefore only defines tests with MIL illumination and stored DTCs as "fail" tests, and only considers MIL illumination (without regard to stored DTCs) in determining whether a vehicle is successfully repaired.

Finally, it should be kept in mind that when reviewing repair analysis results, a failed OBD test record could contain more than one DTC. In Texas, up to 10 DTCs may be stored in the test record, and all stored DTCs were used for this analysis. Therefore, some vehicles will be included in more than one set of results. For example, repair results for vehicles with both oxygen sensor DTCs and catalytic converter DTCs will be included in both the oxygen sensor repair analysis and the catalytic converter repair analysis. Because of the inter-dependence of the various systems (e.g., an oxygen sensor failure may lead to a future catalytic converter failure), distinctions were not made regarding the number or types of DTCs in the original fail records. Rather, vehicles were categorized as "repaired" when the MIL was extinguished and the analyzer assigned an overall OBD pass result, regardless of the number or type of DTCs seen in the initial test failure.

Table 4-7 provides a summary of vehicle repairs (as indicated by OBD fails followed by OBD passes) performed over the period of evaluation. Since this analysis was performed on I/M data collected between January 1, 2012 through December 31, 2013, it is possible that some of the un-repaired vehicles were repaired in 2014. This would increase the "repaired" counts from the numbers shown in this table.

The repair rates for Austin in Table 4-7 are lower than those that were seen for HGB and DFW – in some cases by as much as 20%. A greater fraction of the Austin vehicles that fail are disappearing from the IM program, rather than completing their inspection cycle with a passed inspection.

Table 4-7. System Specific Repair Analysis for Vehicles

Type of Failure (DTC Category)	Total Vehicles Failed (with Indicated Failure Mode DTCs)	Total Repaired Vehicles (MIL Off)		Repaired Vehicles with Failure Mode Monitors Not Yet Set		Confirmed Repairs (Failure Mode Monitors Set)	
Evap System	5,869	4,377	74.6%	2,415	41.1%	1,962	33.4%
O2 Sensor	4,142	2,720	65.7%	107	2.6%	2,613	63.1%
EGR System	2,728	1,825	66.9%	265	9.7%	1,560	57.2%
AI System	368	226	61.4%	53	14.4%	173	47.0%
Catalyst	5,284	3,569	67.5%	900	17.0%	2,669	50.5%

As previously indicated, many vehicles were failed with more than one DTC. Therefore, results from some vehicles may be included in more than one category in Table 4-7. Also, only categories directly monitored with non-continuous monitors are tabulated in Table 4-7. Other failure categories for which readiness status would be more difficult to assess are excluded from the table. Table 4-7 indicates that readiness status may be masking 3% to 41% of vehicles that pass OBD retests based on MIL status with these types of failures. I/M program modifications that would require confirmation of specific failure-mode monitors being set to "ready" would likely reduce the extent of potential false passes but at the expense of a potential increase in motorist inconvenience, especially for difficult to set monitors. ERG is not aware of any programs where this is currently performed.

A comparison was also made between OBD evaporative system results and gas cap test results, on a by-test basis, for all OBD tests conducted during the period of evaluation. Table 4-8 presents a summary of these results.

Table 4-8. Comparison of OBD Evaporative Emission Control System Test Results with Gas Cap Test Results

OBD Evap System Test Results	Gas Cap Test Result				Total	
	Pass		Fail			
Pass	1,697,872	97.7%	16,804	1.0%	1,714,676	98.7%
Fail	21,561	1.2%	752	0.04%	22,313	1.3%
Total	1,719,433	99.0%	17,556	1.0%	1,736,989	100.0%

As can be seen from this table, approximately 1.0% of the tests had failed the OBD portion of the test with evaporative system DTCs, and gas cap failures were seen in 1.0% of the tests. The OBD evaporative system monitoring is designed to be a more comprehensive test since it assesses the integrity of the entire control system, but the OBD evaporative fail rate may be lowered in part by unset evaporative system readiness monitors. Evaporative systems generally require a fairly complex series of vehicle operating conditions before this monitor is set. Although most vehicles passed both tests, very few vehicles (0.04%) failed both tests. Allowable pressure decay limits may contribute to differences in fail rates of the two tests and the lack of overlap between the two tests.

4.5 Average Repair Costs

Both the TIMS and the RERF datasets contain costs for I/M program repairs. For both datasets, repair costs are manually entered. This information was analyzed to provide a rough estimate of the cost of vehicle repairs as a result of the I/M program.

4.5.1.1 TIMS Data

In order to estimate repair costs based on type of repair, repair categories were developed for each vehicle for a given I/M cycle. A repair category is a concatenation of the set of repair types performed in a repair event. In the TIMS data, the five different repairs types listed in Table 4-1 were combined to produce the seven most common repair categories, which account for approximately 99% of all vehicle and I/M cycle combinations. These categories are presented in Table 4-9.

Approximately 60.5%of the repair costs in the TIMS were recorded as $0. There are several possible reasons for this, including inaccurate repair data entry during a vehicle reinspection, motorists performing their own repairs, lack of repair data available during a vehicle reinspection, or vehicles receiving a retest without receiving repairs. Because of the large number of repair records affected, no attempt was made to correct the costs as part of this analysis. Nonetheless, the existence of so many repair costs with a value of $0 significantly affected the average and median repair values calculated. Table 4-9 presents the number of records with a cost of $0 by repair category. Note that about 20-40 % of most slates listed contained $0 repair costs, but fuel system and miscellaneous repairs contained a much higher percentage (about 63.0% and 70.5%, respectively).

It was also noted than many of the repair costs listed in the TIMS data seemed to be unusually large; many records were in excess of $2000, with some approaching $60,000. It is suspected that these repair costs reflect invalid data entry by inspectors during vehicle reinspections. Figure 4-1 presents a histogram of repairs that cost more than $2000.

Table 4-9. TIMS Records with a Repair Cost of $0, by Category

Repair Category	Cost > 0	Cost = Zero	Total	% of Cost = 0
Fuel System and Emissions System	96	55	151	36.42
Emissions System & Miscellaneous	182	59	241	24.48
Engine Mechanical	243	88	331	26.59
Ignition / Electrical System	712	418	1130	36.99
Fuel System	1980	3366	5346	62.96
Miscellaneous	3777	9032	12809	70.51
Emissions System	3452	2957	6409	46.14
Total (of Selected Repair Slates)	*10442*	*15975*	*26417*	*60.47*

Table 4-10 presents median and mean repair costs for each of the repair types specified in the TIMS. Mean and median are calculated twice – once including the $0 and >$2000 repair costs found in the dataset (unedited), and once without (edited). According to the unedited dataset, vehicle owners 26,808 repairs while spending approximately $2.16 million. According to the edited dataset, which leaves out $0 cost and greater than 2,000 cost observations, vehicle owners performed 10,648 repairs while spending almost $1.88 million.

Figures 4-2 and 4-3 present mean repair costs by inspection year and model year, for both the unedited and edited TIMS datasets. There is a significant amount of variability in the unedited data when compared to the edited data. As shown by these plots, repair costs as a whole have not increased from year to year. Due to the limited control in repair data entry and the large number of suspect values in the TIMS repair data, these results may be significantly different from true repair costs in the Texas I/M program.

Figure 4-1. Repairs with Cost Greater than $2000

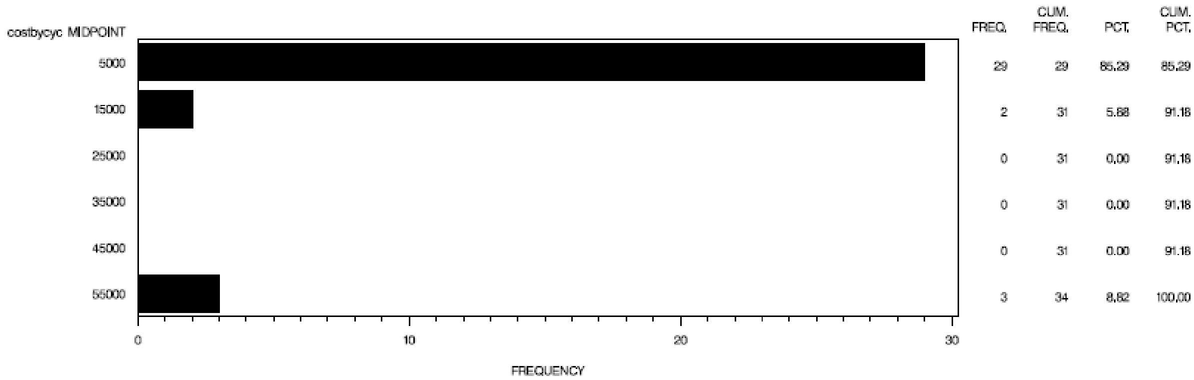


Table 4-10. Average Repair Costs

Year of Inspection	Repair Category	Original Dataset			Costs Between $0 and $2000		
		Number of Repairs	Median Repair Cost	Mean Repair Cost	Number of Repairs	Median Repair Cost	Mean Repair Cost
2012	Fuel System and Emissions System	89	$163.25	$255.99	67	$233.50	$340.04
2012	Emissions System & Miscellaneous	111	$120.00	$220.18	87	$170.00	$252.19
2012	Engine Mechanical	186	$150.00	$307.36	142	$190.00	$304.78
2012	Ignition / Electrical System	620	$50.00	$158.91	398	$114.50	$200.42
2012	Fuel System	2971	$0.00	$70.14	1216	$50.00	$116.85
2012	Miscellaneous	3212	$2.00	$156.80	1852	$180.00	$263.94
2012	Emissions System	6815	$0.00	$42.48	2025	$40.00	$99.94
2013	Fuel System and Emissions System	62	$0.00	$170.07	29	$150.00	$363.60
2013	Emissions System & Miscellaneous	130	$60.00	$173.31	94	$166.88	$239.68
2013	Engine Mechanical	145	$128.00	$305.77	95	$250.00	$371.19
2013	Ignition / Electrical System	510	$39.50	$124.32	312	$125.00	$203.21
2013	Fuel System	2375	$0.00	$38.34	761	$50.00	$119.64
2013	Miscellaneous	3196	$0.00	$147.91	1590	$180.00	$290.44
2013	Emissions System	5994	$0.00	$32.39	1739	$22.00	$76.08

Figure 4-2. Mean Repair Costs by Model Year and Inspection Year (Unedited Dataset)

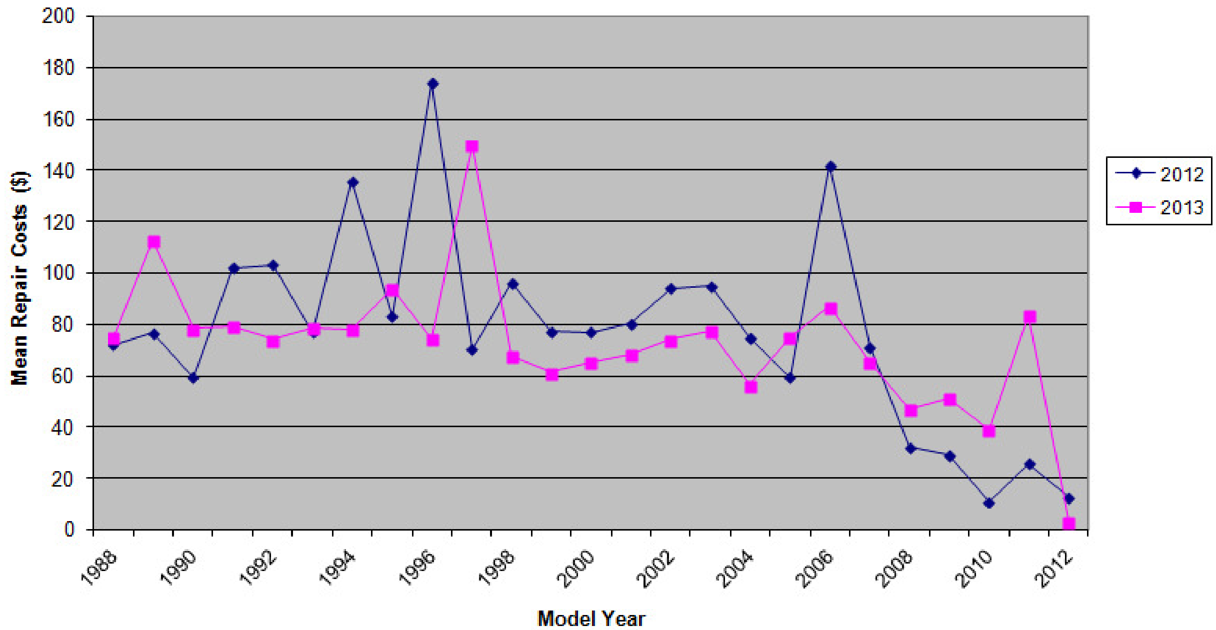
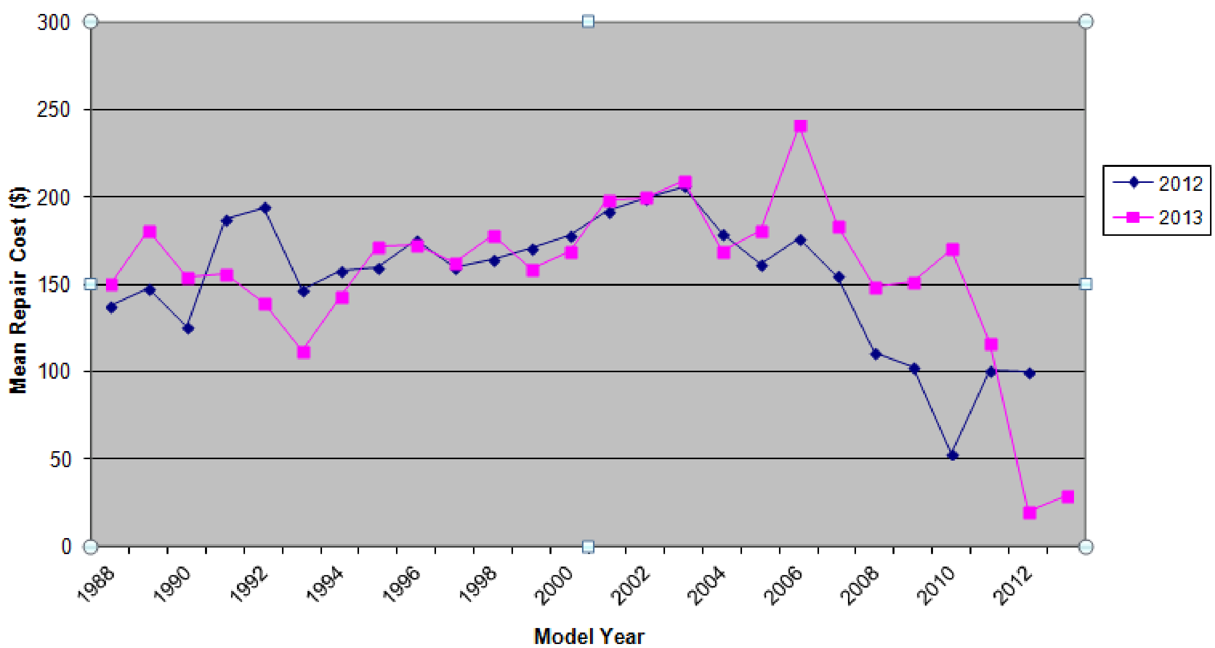


Figure 4-3. Mean Repair Costs by Model Year and Inspection Year (Edited Dataset)



Figures 4-4 and 4-5 present the percentile distribution of repair costs for the most common TIMS repair categories, for both the unedited and edited datasets. The unedited data contains repairs with an average cost of $0 for all repair slates, but miscellaneous repairs costing $0 extend close to the 70th percentile, considerably more than the other categories.

For both datasets, the range of average costs was most limited for miscellaneous repairs, while the greatest variation in average costs was visible in repairs performed on both the fuel and emissions systems.

Figure 4-4. Distribution of Repair Costs by Category (Unedited Dataset)

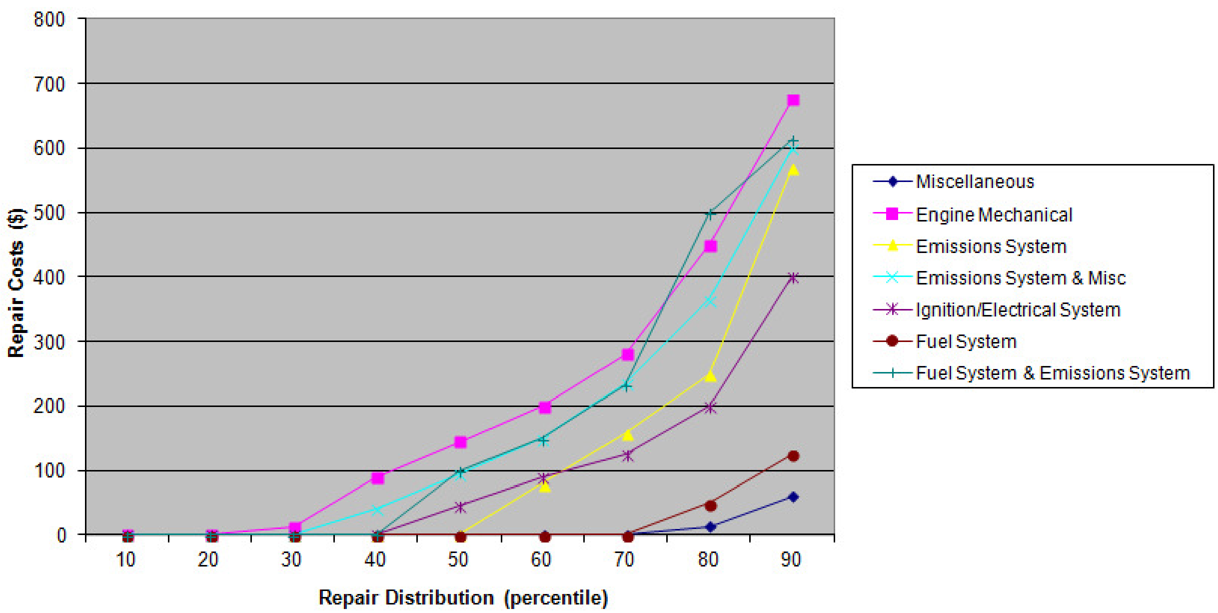
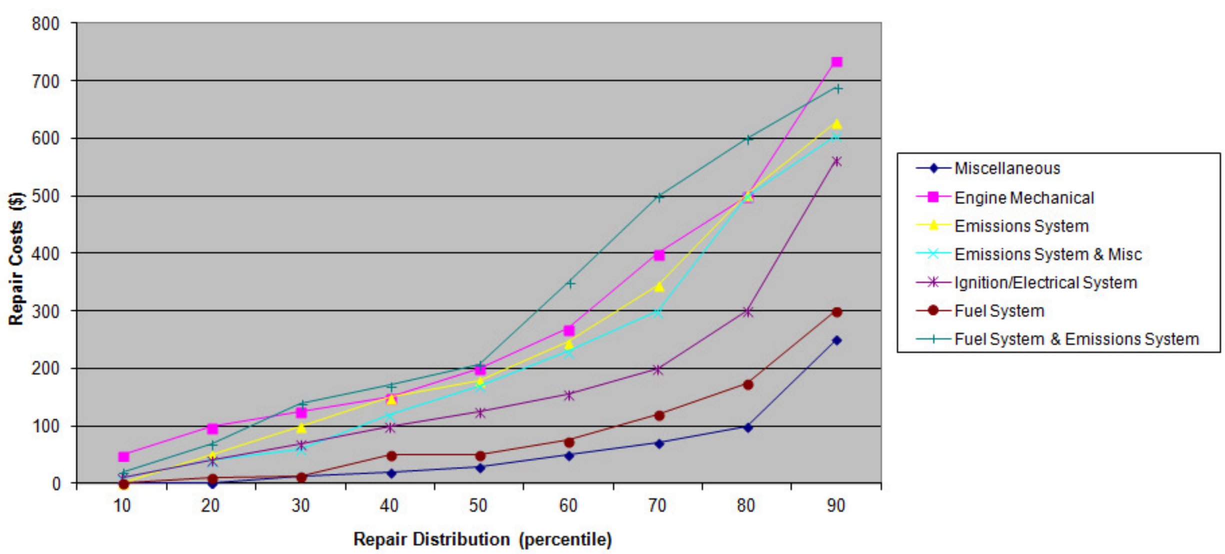


Figure 4-5. Distribution of Repair Costs by Category (Edited Dataset)



4.5.1.1 RERF Data

Analysis of the RERF data indicates vehicle owners spent over $146,000 on 268 repairs at RERFs, resulting in mean and median repair costs of $572 and $548, respectively. These results were obtained from data collected from repair summary data submitted to DPS by repair shops participating in the recognized repair facility program.

In order to estimate repair costs based on type of repair, repair categories (referred to as repair slates) were developed for each vehicle for a given I/M cycle. As with the TIMS data analysis, a repair category is a concatenation of the set of repair types performed in a repair event. In the RERF data, the different repair types listed in Table 4-2 were combined to produce the nine most common repair slates. To simplify the aggregation of individual repairs into meaningful repair slates, some repairs were combined into a single "sub-category". The most common repair categories observed are presented in Table 4-11.

Table 4-11. Common RERF Repair Categories

Repair Category	Frequency	Percent
Transmission	2	1.26
Injection System & Catalyst	1	0.63
O2 Sensor & Catalyst	2	1.26
Fuel System	5	3.14
Emissions System	1	0.63
O2 Sensor	5	3.14
EGR	6	3.77
Evap System	13	8.18
Other Repair Slates	114	71.7

Table 4-12 presents median and mean repair costs for each of the repair slates developed using data in the RERF dataset.

Table 4-12. RERF Repair Category Average Costs

Year of Inspection	Repair Category	Number of Repairs	Median Repair Cost	Mean Repair Cost
2012	Catalyst	9	$630	$739
2012	EGR	5	$544	$512
2012	Emissions System	1	$294	$294
2012	Evap System	13	$487	$448
2012	Fuel System	5	$629	$483
2012	Injection System & Catalyst	1	$630	$630
2012	O2 Sensor	5	$386	$375
2012	O2 Sensor & Catalyst	2	$630	$630
2012	Other Repair Slates	88	$557	$532
2012	Transmission	2	$1,091	$1,091

Figure 4-6 presents mean repair costs by inspection year and model year, for the RERF TIMS dataset. Average repair costs tend to fall in the $400 - $650 range, which is significantly higher than the $150 - $200 range seen in the TIMS data.

Figure 4-6. Mean Repair Costs by Model Year and Inspection Year – RERF

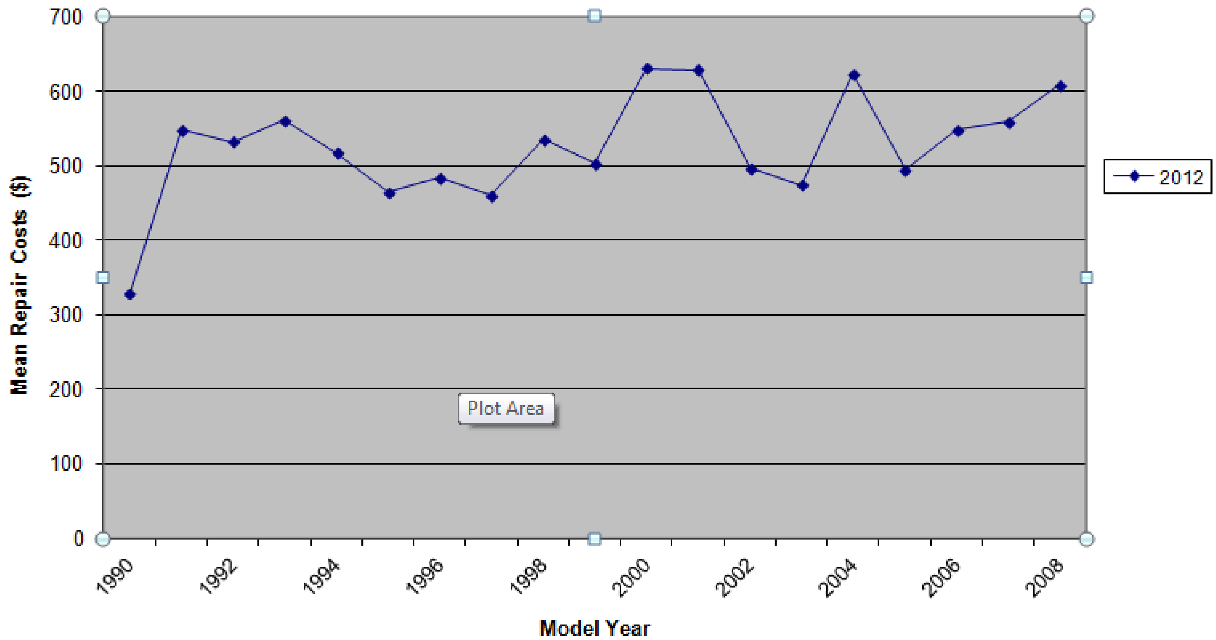
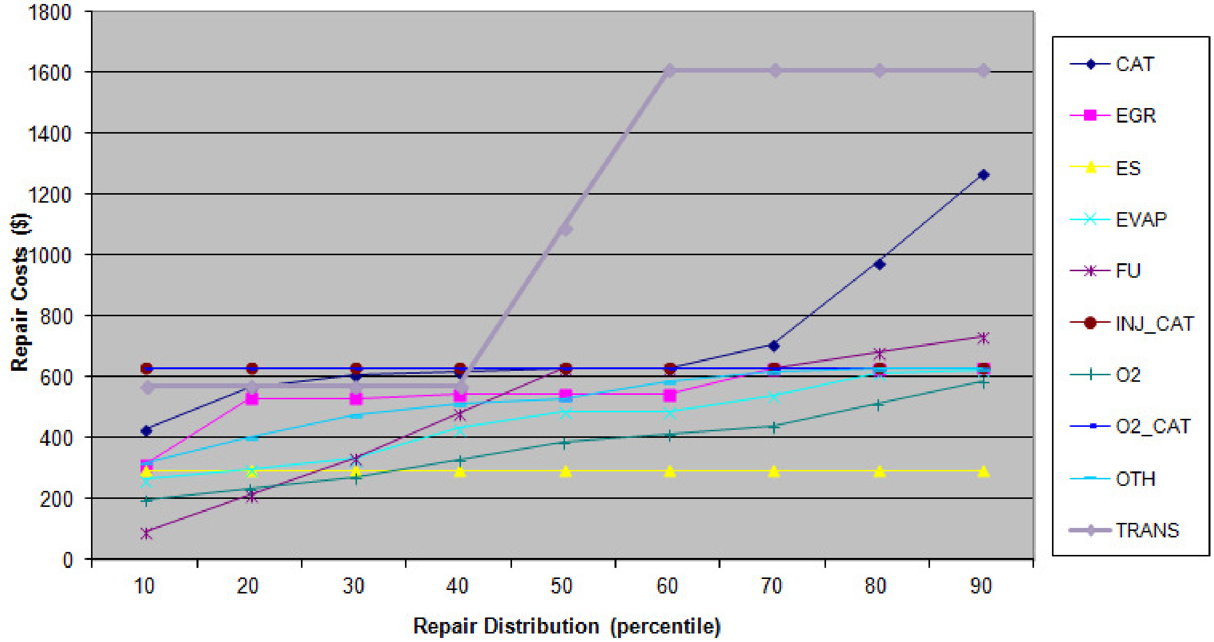


Figure 4-7 presents the percentile distribution of repair costs for the most common RERF repair slates. Transmission repair costs are a clear outlier here.

Figure 4-7. Distribution of Repair Costs by Category - RERF



There is a large difference in the TIMS vs. RERF average repair cost data. As noted, obtaining accurate repair data is difficult and this certainly contributes to the problem. However, another explanation may be that the repair costs for RERF stations is higher than average repair stations since these stations voluntarily participate in the RERF program and, therefore, are more likely to make repairs that are more technically challenging and, more expensive. It is also possible that the inspection technicians are less likely to enter accurate repair cost data because unlike the RERF technicians they have no first-hand knowledge of the repair and the RERF technicians realize that repair cost data is used to rank their facility and this motivates them to be more conscientious in filling out the repair form.

5.0 Estimates of I/M Benefits

The Annual Benefit is the size of the fleet's "saw tooth" emissions profile that occurs during each cycle as the vehicles in the fleet are repeatedly inspected and repaired. The saw tooth is produced for each vehicle by the annual change in emissions downward from I/M-induced repair and then upward from emissions degradation during the long period before the next I/M cycle. The analyses presented in Sections 5.1 and 5.2 are annual benefits based on the TIMS data alone (Section 5.1) or pairing the TIMS data with remote sensing (RS) data (Section 5.2).

5.1 Estimate of Annual I/M Benefit from TIMS Data

ERG used two years of the TIMS data to calculate the Annual Benefit of the I/M program. Although using TIMS or in-program data is often done for estimating the Annual I/M Benefit, the approach has at least two inherent problems, which are described below. In spite of these problems, the TIMS data was used to estimate the Annual I/M Benefit because it is relatively easy to do.

The first problem is a consequence of using the fast-pass ASM algorithm in the I/M program. This does not apply to the TSI inspections that are performed in the Austin I/M program. The other source of bias is produced by regression toward the mean. Because of the emissions variability of the ASM or TSI measurements, vehicles that fail the inspection tend to have a positive random error component in their measured emissions values. This means that the calculated average difference between the before-repair test value and the after-repair test value for the dataset will almost always show a decrease even if the repairs produced no real emissions benefit. For this analysis, there was no correction made for this regression-toward-the-mean effect. Accordingly, regression toward the mean tends to overestimate the calculated benefit of I/M-induced repairs.

The TIMS contains emissions measurements obtained from a vehicle when it first is inspected for its annual inspection and emissions measurements after it has been repaired and meets the Texas I/M requirements. The difference between these two emissions can be expected to represent the improvement in emissions as a result of the repairs. The sum of all of these emissions changes for all vehicles that received repairs are an estimate of the Annual I/M Benefit using in-program data. Note that this difference is measured by the difference in emissions before and after the I/M inspection. Therefore, it represents the change in emissions concentration only at the inspection event. It does not measure the increase in emissions caused by emissions degradation between annual inspection cycles.

Four I/M sequence categories were considered in this analysis. All the various failure patterns described in Section 3.3 were combined into these four categories for the purposes of calculating the Annual I/M Benefit. The I/M sequence categories are as follows:

- Single Pass (1P) – A vehicle completes its annual I/M requirement with a pass on the first inspection.
- Single Fail (1F) – A vehicle receives a single inspection, and it is a fail. The dataset does not contain any evidence that the vehicle returns or any information that it may have been waivered.
- Initial Fail, then Final Fail (FF) – A vehicle fails its first annual emissions inspection and then, perhaps after a series of repairs and re-inspections, fails its last annual inspection. Waivers are flagged separately, but are not removed from these calculations.
- Initial Fail, then Final Pass (FP) – A vehicle fails its first annual emissions inspection and then ultimately passes its last annual inspection to meet the I/M requirements.

The largest numbers of sequences in the evaluation period were 1Ps since most vehicles pass their initial inspection each year. 1Ps make up about 95.2% of all sequences. The FP sequences are the next most common and make up about 4.1% of all sequences. The 1F and FF sequences are less common and make up 0.5% and 0.04% of the sequences. Since vehicles with 1P and 1F sequences are tested only initially (because there is only one test), the final emissions values equal the initial emissions values. Consequently, vehicles with 1P and 1F sequences do not contribute to the calculated Annual I/M Benefit. The vehicles with FF sequences do have different values for the initial and final average emissions; however, the values are not greatly different, which is probably because repairs to these vehicles were not entirely successful.

ERG calculated the average emission values using completed I/M cycles and presented the results in various ways. Table 5-1 documents the average emission concentration values for TSI tests in the Austin I/M program area during this evaluation period (2014 report covering 2012 and 2013 program years). The values also show the measured average change in emissions concentrations at the inspection events. In the last row of the table it can be seen that TSI HC decreased 18 to 20%, and TSI CO decreased 21 to 23%. As described above, these changes are confounded by the effect of regression toward the mean (which tends to overestimate the program's emission reduction). These averages include all four of the I/M sequence categories of 1P, 1F, FF and FP, but the focus of the analysis below is on the 1P and FP categories as they constitute the great majority of the data.

These concentrations for the TSI inspection are similar to those that were seen for TSI inspections in the DFW/HGB program areas.

The second block of data in Table 5-1 shows the emissions averages for the I/M program areas categorized by the two major I/M sequence categories, 1P and FP. These two categories make up over 98% of the I/M sequences in the datasets. The table shows that, of course, for the 1P category the change in emissions is 0% since these vehicles simply initially pass. However, for the FP category, the TSI measurements show large emissions decreases from 76 to 83%. These are emission reductions of the vehicles that were failing when they entered the sequence, were repaired, and left the sequence as passing vehicles. Thus, these vehicles are the source of the Annual I/M Benefit. The apparent changes in the emissions concentrations as a result of repair are substantial for the FP sequences.

Another observation that can be made from the data in Table 5-1 is that the final concentrations of the FP vehicles are comparable to, but slightly larger than, the final concentrations of the 1P vehicles. This seems to indicate that vehicles that fail initially can be repaired to produce large emissions reductions, but as a group, they cannot be repaired to emission levels as low as vehicles that initially pass. One of the factors that complicate this comparison is that the technologies of the 1P vehicles and FP vehicles are probably quite different.

Table 5-1. 2014 Report Annual I/M Benefit Using TIMS Data for TSI Emissions

TSI HC (ppm)								
			Curb			**High**		
Area	**Seq.**	**Count**	**Initial**	**Final**	**% Change**	**Initial**	**Final**	**% Change**
AUS	1P	78,002	81	81	0.0%	40	40	0.0%
	FP	5,166	463	110	76.2%	261	59	77.4%
	1P+FP	85,815	117	96	17.9%	61	49	19.7%
TSI CO (%)								
AUS	1P	78,002	0.17	0.17	0.0%	0.21	0.21	0.0%
	FP	5,166	1.6	0.27	83.1%	1.47	0.31	78.9%
	1P+FP	85,815	0.3	0.23	23.3%	0.33	0.26	21.2%

5.2 Estimate of the Annual I/M Benefit from Paired I/M and RS Data

The Annual Benefit is the size of the fleet's "saw tooth" emissions profile that occurs during each cycle as the vehicles in the fleet are repeatedly inspected and repaired. The saw tooth is produced for each vehicle by the annual change in emissions downward from I/M-induced repair and then upward from emissions degradation during the period before the next I/M cycle. The analysis presented in this section estimates annual benefits based on pairing the TIMS data with RS data.

Although the effect of the I/M program is to reduce emissions by repairing vehicles that fail an emissions test, these vehicles will then likely have increasing emissions until their next I/M test. This is also true for passing vehicles. RS data allows this slow increase in emissions to be observed as it can be seen that initially passing vehicles (95% of the fleet) go through the I/M program and their emissions gradually increase each year. This is often called emission creep. Eventually, when their emissions have increased over the years to a high enough level, the I/M cutpoint is tripped and repairs are done. During all of those previous years the emissions of the initially passing vehicles have been allowed to increase unchecked. More-stringent cutpoints should help reduce the number of vehicles that are allowed to go through the I/M program unchecked as their emissions profile deteriorates. However, more-stringent cutpoints would also cause an increase in the number of vehicles failed when the vehicles have no problem that can be identified. And it must be remembered that increasing cutpoint stringency is only possible with tailpipe testing, not OBD.

ERG used RS data taken in the I/M areas to determine the Annual I/M Benefit produced by the I/M program. This was done by pairing RS data with the TIMS inspection data by vehicle, and comparing the before-I/M and after-I/M RS levels.

A vehicle can be measured by RS at any time before or after its annual I/M inspection. By aligning all of the RS measurements with respect to the time of I/M repair, the average of the RS measurements will reveal the change in emissions produced by the I/M program and the rate of emissions degradation between I/M inspections. However, it is important to understand that the set of vehicles with RS measurements before the I/M inspection does not contain the same vehicles as those with RS measurements after the I/M inspection. Because of the large emissions variability of emissions measurements, the average RS emissions versus time before and after I/M inspection will have a considerable amount of variability even when millions of RS observations are used. Nevertheless, the calculation provides an estimate of the benefits of the I/M program that is independent of the I/M program itself.

Preparation of RS Data – In this task, we used the RS data for vehicles registered in the Austin I/M area. The goal was to use the RS data already being collected by the Texas Department of Public Safety (DPS) as an independent means of measuring the benefit.

The RS data provided by DPS started out with about 2.4 million records, collected from January 1, 2012, through December 31, 2013. In previous years of performing this type of analysis, some records with no license plate were included in the dataset and were deleted. However, all of this year’s records contained the license plate.

This analysis evaluates the inspection and maintenance programs in the Austin areas. The RS records were collected in all I/M areas within the state of Texas including the El Paso, Williamson, and Travis counties. Therefore, only RS data for Austin vehicles were kept in the dataset. This left 79,000 RS records.

The RS records provided to ERG did not contain any information about the vehicle except the license plate number. For the Comprehensive Method [Reference 2] calculations, it is important to determine the fleet characteristics of the vehicles measured by RS in the I/M area. Therefore, it was important to determine the vehicle characteristics such as age, technology, and odometer. The potential sources of this information were the registration data, the I/M data, and the ERG VIN decoder. The records from the I/M program do contain odometer and other vehicle characteristics information; however, there are no I/M records for vehicles registered outside the I/M areas. The registration data contained vehicle make and model year but did not contain odometer, vehicle technology information, or vehicle odometer information. Because of this, the vehicle odometer could not be used in the comparison of fleet characteristics. In the 2006 performance of this analysis, the ERG VIN decoder was used to provide the vehicle characteristics information which included vehicle make, model year, type (car or truck), metering, and emission control systems. However, in the 2009 Report, limiting the RS dataset to only those records that had a successful match to a VIN-decoder result dropped the number of RS records from 6.2 million to 3.5 million records – a significant reduction. Also, in the 2006 analysis, the vehicle technology information that comes exclusively from the VIN decoder did not get used in the final analysis procedure. The only stratification variable was the vehicle model year, which is available from the registration records. Therefore, for the current analysis, it was decided not to use the VIN decoder results to obtain additional vehicle information.

The RS records provided to ERG by DPS were already checked for validity by the RS data collection contractor. Therefore, there was no check made for the validity of the values within each of the RS data fields. However, the vehicle specific power (VSP) for each vehicle using the RS speed, acceleration, and the slope at the RS site was calculated. The slope for the RS site was not included in the RS data. These data were provided separately by DPS. Once the sites and slopes were matched to the RS records and the VSP calculations were done, a VSP filter was applied. Any records with a VSP outside the range of 5-25 kilowatt per ton were removed from the dataset. This left 62,000 records.

The calculation of the Annual I/M Benefit was done using the Comprehensive Method outlined by the EPA. [Section 6.2 of Reference 2] In this method, RS data taken in the I/M area is paired with I/M inspections by vehicle.

ERG calculated the time between the RS reading and the I/M test and placed each observation into a month bin – for example, 1 month before the initial test, 2 months before the initial test, 3 months before initial, 1 month after the final test, 2 months after the final test, 3 months after final, etc. Any RS readings that occurred within the I/M cycle, that is, between the initial test and the final test, were removed from the analysis, because for these mid-cycle observations it was not possible to determine the state of repair of the vehicle at the time of the RS measurement.

ERG also created a variable to describe the sequence of I/M inspection results for each vehicle inspected. There were four I/M sequence categories outlined in the EPA's description of the Comprehensive Method calculations: 1) vehicles that passed their initial I/M tests (1P), 2) vehicles that failed their initial I/M test and then eventually passed (FP), 3) vehicles that failed their I/M test and did not come back for another test (1F), and 4) vehicles that failed their I/M test and failed all other subsequent I/M tests (FF).

The average RS concentrations for HC, CO, and NO_x by month bin, by I/M sequence category, and also by model year group were examined. Because the Texas I/M program is an annual program, the plots were limited to only the RS matches that happened up to 6 months before and 6 months after the I/M test. The HC, CO, and NO_x plots for the entire Austin dataset are shown in Figures 5-1 through 5-3. These figures show the RS averages (indicated by the dots) and the uncertainties associated with these averages at a 95% confidence level (indicated by the lines). Note that the dataset is very small as compared with the datasets used for similar analysis for the HGB and DFW areas, so there is quite a bit of uncertainty and scatter shown in the plots.

Figure 5-1. Average RS HC Versus Month from the I/M Test RS Readings from the AUS Area

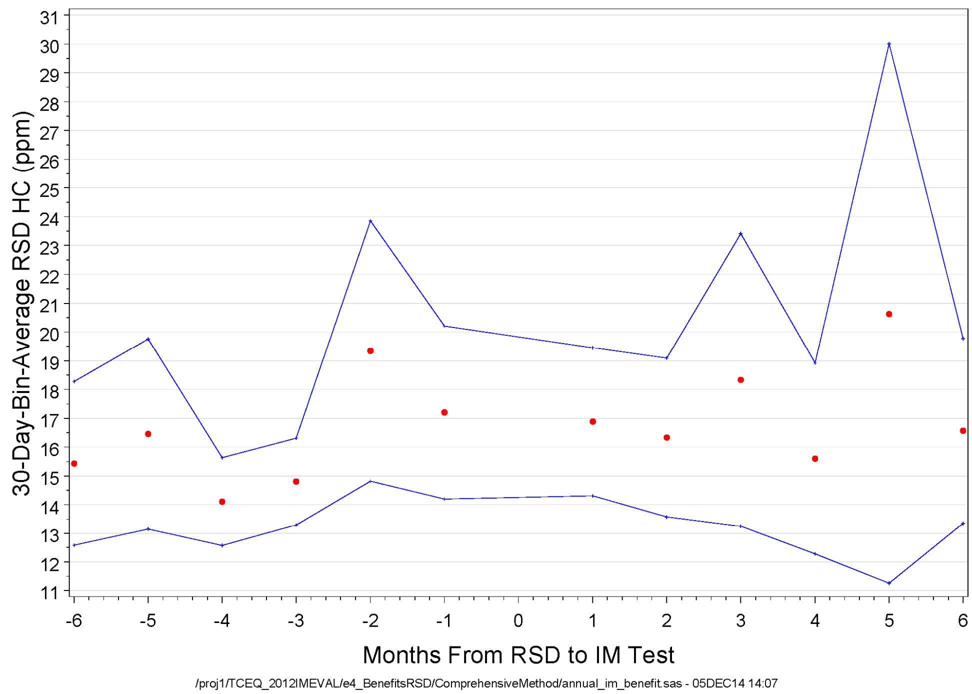


Figure 5-2. Average RS CO Versus Month from the I/M Test RS Readings from the AUS Area

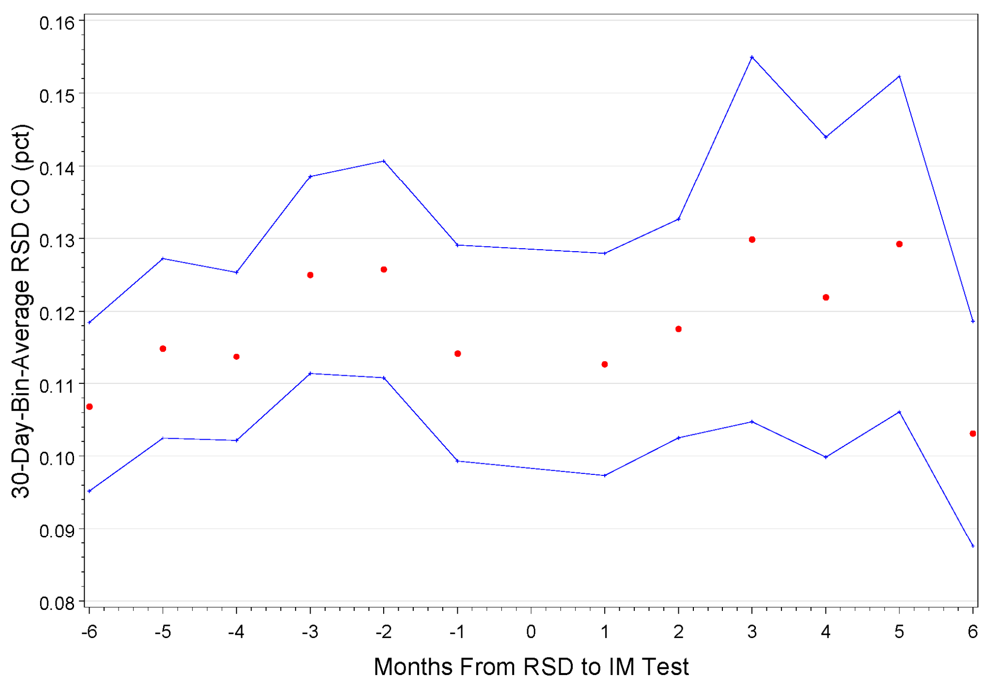
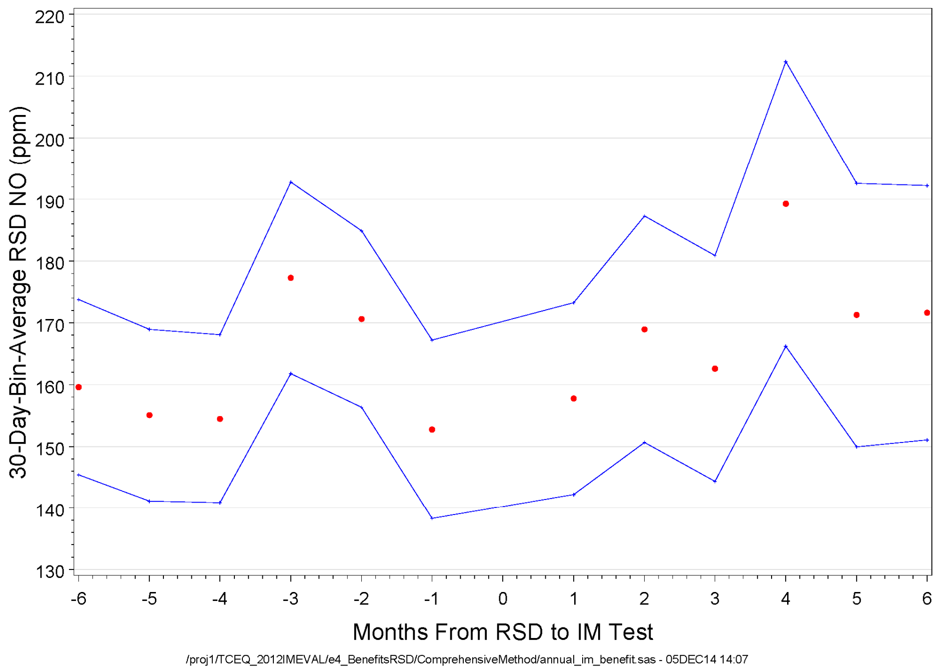


Figure 5-3. Average RS NO_x Versus Month from the I/M Test RS Readings from the AUS Area



These figures above do not show a drop in the average RS emissions from before to after the I/M test. However, when the plots are done on a dataset that has been stratified by the I/M sequence category, some I/M benefits start to become evident. Table 5-2 shows the number of records in the RS-matched-with-I/M dataset that fall into each I/M sequence category. The table clearly demonstrates that the 1P and FP I/M sequence categories dominate the I/M program. At this point, the separate effects of the 1P and FP categories are examined.

Table 5-2. Number of Vehicles in Each I/M Sequence Category for the Dataset of RS Events Matched with I/M Tests

	Austin	
I/M Sequence Category	**Number of Vehicles**	**Percent**
1P	46,451	95.7%
FP	1,887	3.9%
PP	219	0.5%
FF	4	0.0%
Total	48,561	100.0%

The plots of mean RS concentrations versus time from I/M inspection were repeated, this time separately for the 1P and FP categories. Figures 5-4 and 5-5 show the time trend of the monthly average RS HC for the Austin area vehicles that passed initially (1P), and that failed initially and then ultimately passed (FP). Below these figures are Figures 5-6 through 5-9 with similar plots for CO and NOx.

The 1P plots, which describe 95.7% of the vehicles in the Austin area, show small emission increases from the month before to the month after the I/M test. There is no evidence of a decrease in emissions in the two months before the I/M inspection that could be attributed to pre-inspection repairs. If anything, the long term time trend is generally upward, which may be attributed to the general long term emissions deterioration of these vehicles.

The FP plots, which describe 3.9% of the vehicles in the Austin area, or 1,800 vehicles, were expected to show downward jogs in the emissions at the time of the I/M inspection, or just following the inspection. Unfortunately, with so few vehicles in the dataset, the scatter is high enough that trends are not readily apparent.

Figure 5-4. Average RS HC vs. Month After the I/M Test for AUS Vehicles with I/M Sequence Category = 1P

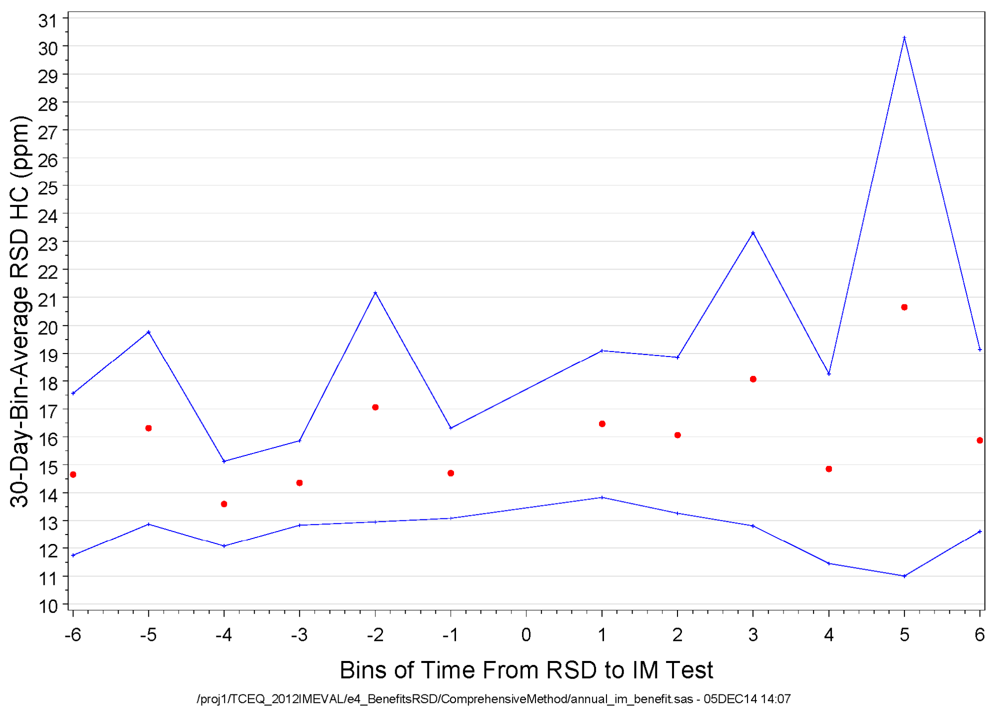


Figure 5-5. Average RS HC vs. Month After the I/M Test for AUS Vehicles with I/M Sequence Category = FP

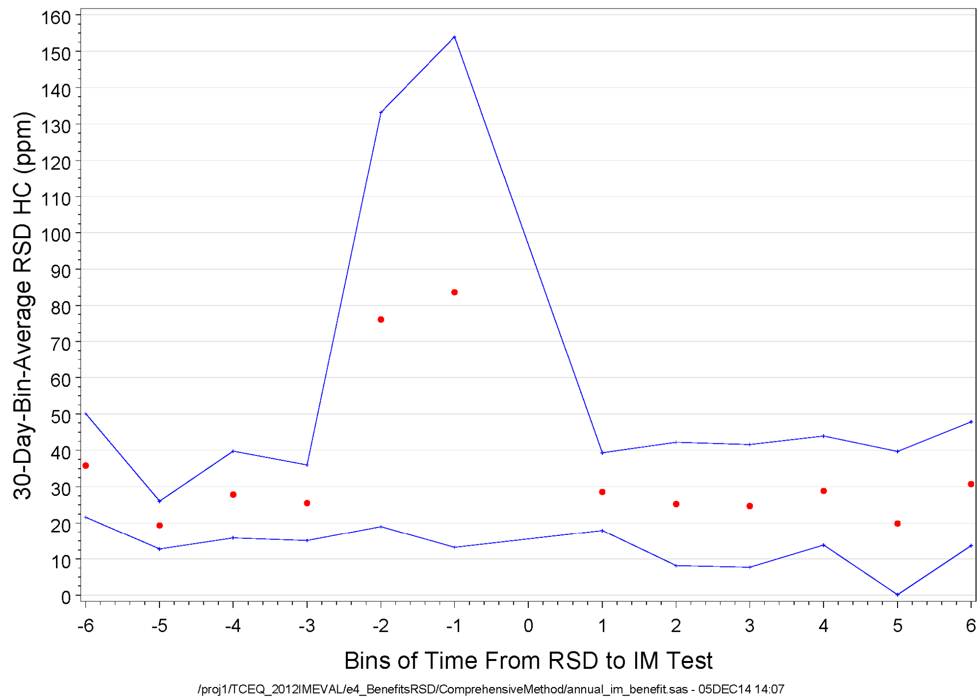


Figure 5-6. Average RS CO vs. Month After the I/M Test for AUS Vehicles with I/M Sequence Category = 1P

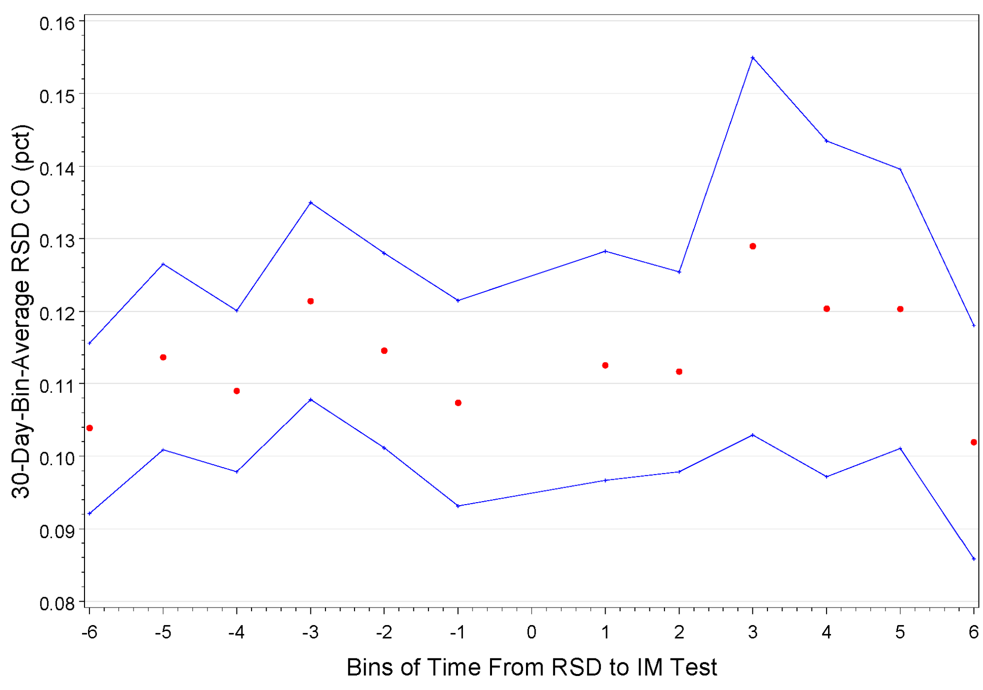


Figure 5-7. Average RS CO vs. Month After the I/M Test for AUS Vehicles with I/M Sequence Category = FP

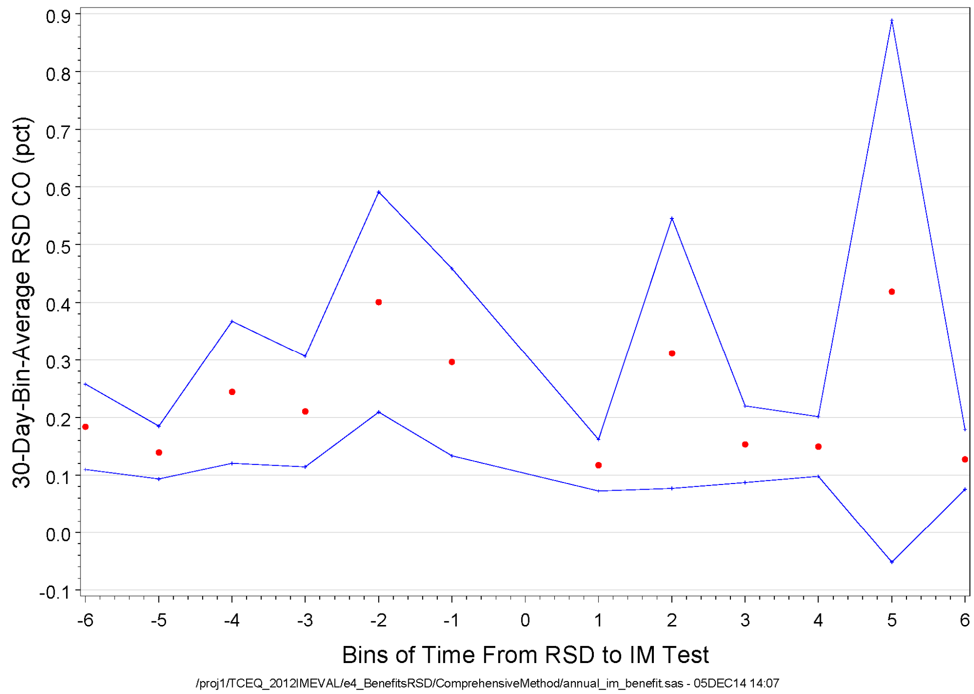


Figure 5-8. Average RS NO_x vs. Month After the I/M Test for AUS Vehicles with I/M Sequence Category = 1P

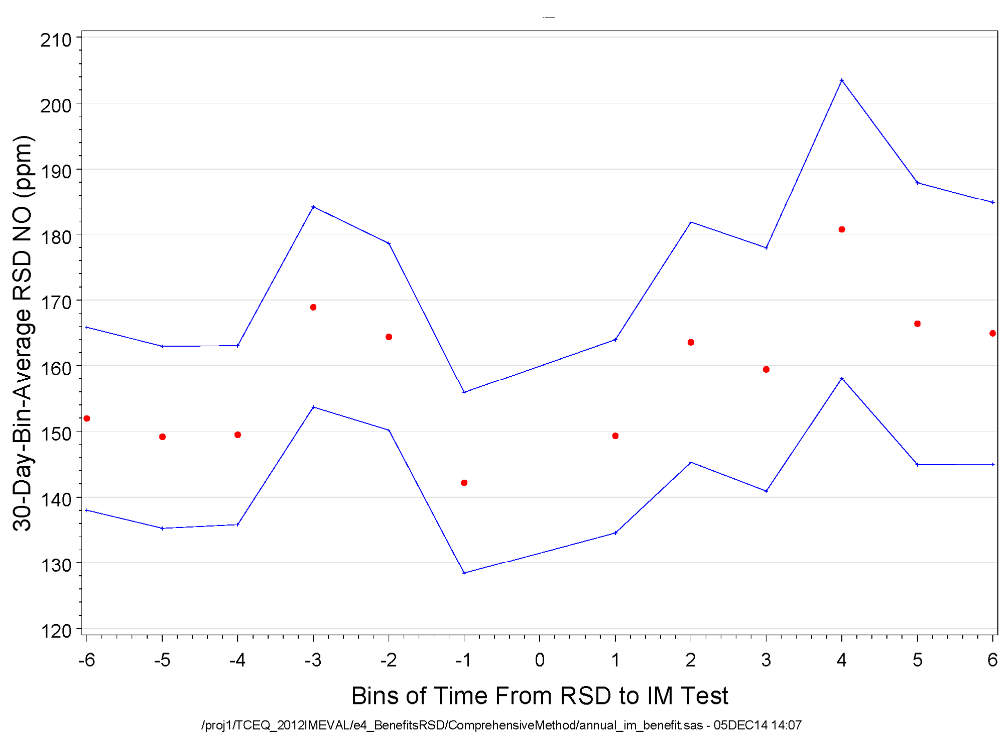
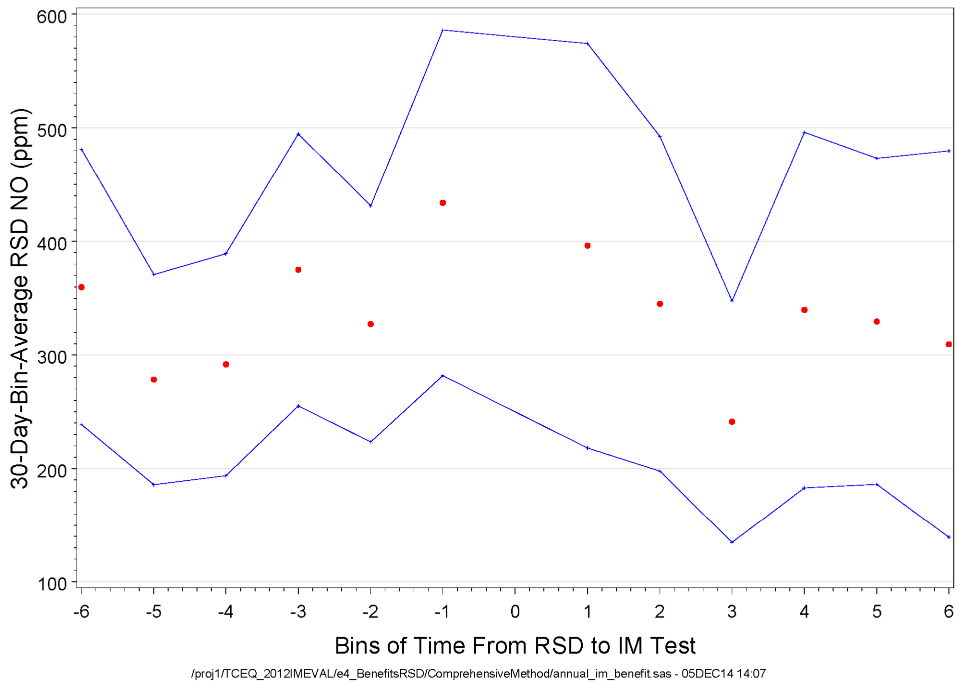


Figure 5-9. Average RS NO_x vs. Month After the I/M Test for AUS Vehicles with I/M Sequence Category = FP



To quantify the Annual I/M Benefit, the month bins were combined to obtain a single average RS concentration before the I/M test and another average RS concentration after the I/M test. The before bin consists of all RS measurements that happened between 31 and 90 days prior to the initial I/M test. The RS measurements that happened from 1 to 30 days prior to the I/M test were not included in the bin to minimize the effect of pre-inspection repairs on the before average. This binning methodology was suggested by the EPA in the documentation for the Comprehensive Method. The after bin contains all RS tests that happened between 1 and 90 days following the final I/M test.

The calculations for the before and after I/M RS averages were done for the entire RS matched I/M dataset for each of the two major I/M sequence categories, FP and 1P, and averages were calculated separately by model year group. At the beginning of this analysis, when the fleet characteristics of the I/M fleet were compared to the fleet characteristics of the set of vehicles with RS measurements matched to I/Ms, the RS-matched fleet was found to contain a larger percentage of new vehicles. Therefore, each of the I/M category bins were also separated by model year group. The benefit for each model year group could be weighted by the percentage of vehicles in each model year group in the I/M fleet to translate the benefits observed in the RS-matched fleet to the I/M fleet.

These before and after I/M average RS measurements for the FP vehicles and the 1P vehicles were plotted for the Austin area in Figures 5-10 through 5-15. Each plot contains a separate line for each of four model year groups, with the before I/M RS measurement on the left and the after I/M RS measurement on the right. The lines highlight the differences between these RS averages and the error bars show the 95% confidence level uncertainties for the respective averages. The plots for FP vehicles in Figures 5-10 to 5-12 show that, at least for the oldest model year group of vehicles, the HC and CO emissions of FP vehicles decrease. However, the NOx emissions of FP vehicles increase (NOx is not tested in the TSI inspection). However, the decreases may not be statistically significant due to the small number of vehicles in that group. The plots for 1P vehicles in Figures 5-13 to 5-15 show that in some cases the emissions of 1P vehicles increase across the I/M inspections; however, in many cases the increase is not statistically significant.

Figure 5-10. Average RS HC by Model Year Group Before and After I/M Test for AUS Vehicles with I/M Sequence Category = FP

Figure 5-11. Average RS CO by Model Year Group Before and After I/M Test for AUS Vehicles with I/M Sequence Category = FP

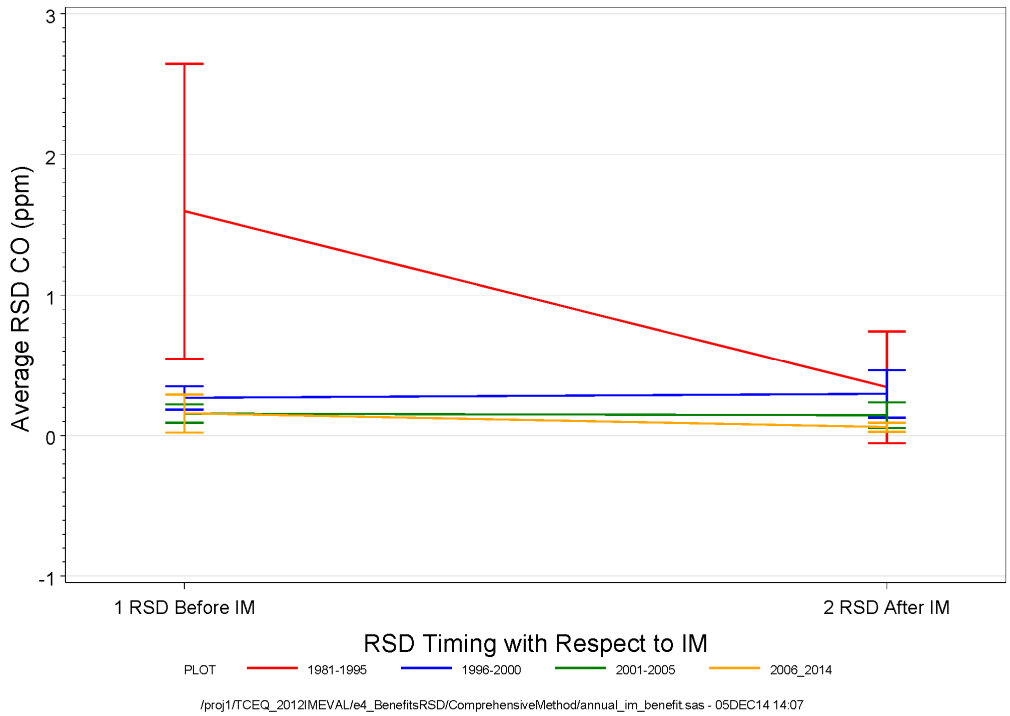


Figure 5-12. Average RS NOx by Model Year Group Before and After I/M Test for AUS Vehicles with I/M Sequence Category = FP

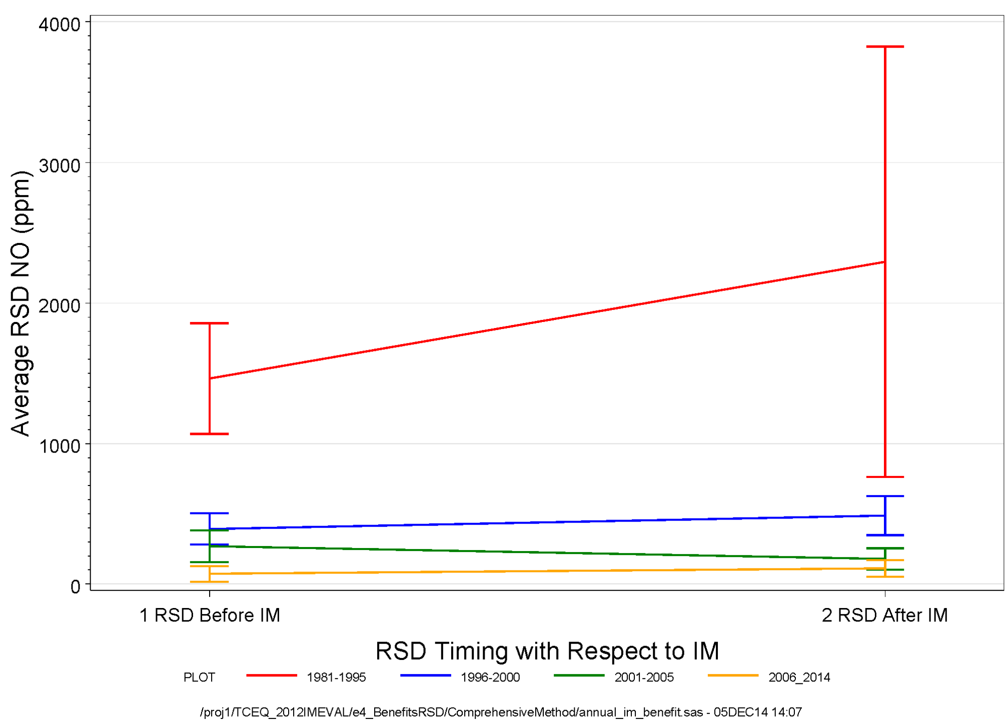


Figure 5-13. Average RS HC by Model Year Group Before and After I/M Test for AUS Vehicles with I/M Sequence Category = 1P

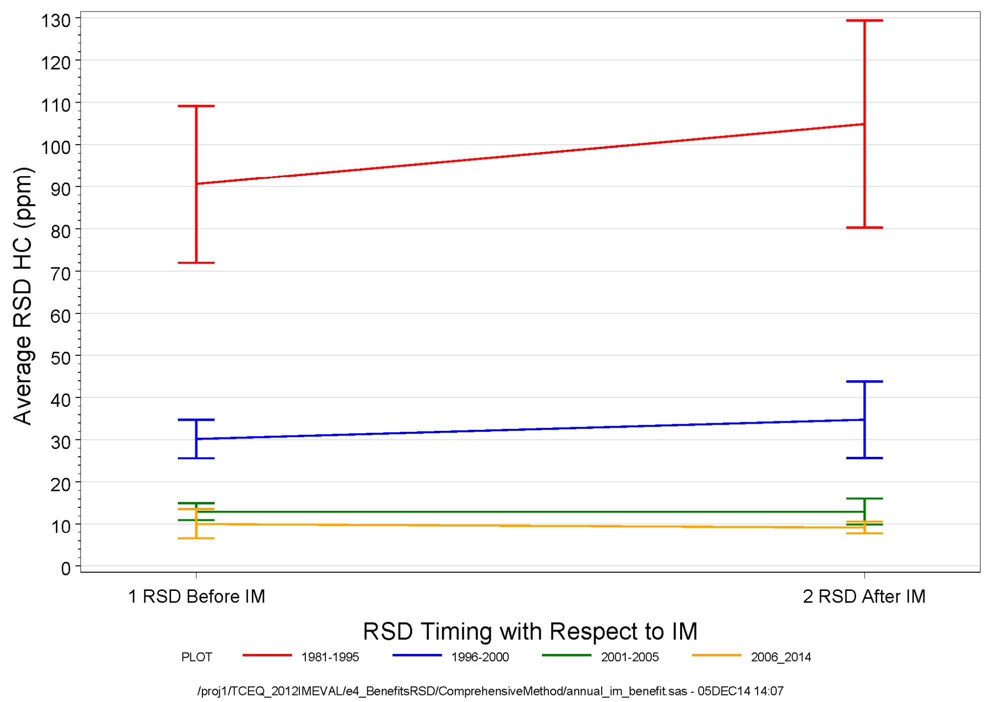


Figure 5-14. Average RS CO by Model Year Group Before and After I/M Test for AUS Vehicles with I/M Sequence Category = 1P

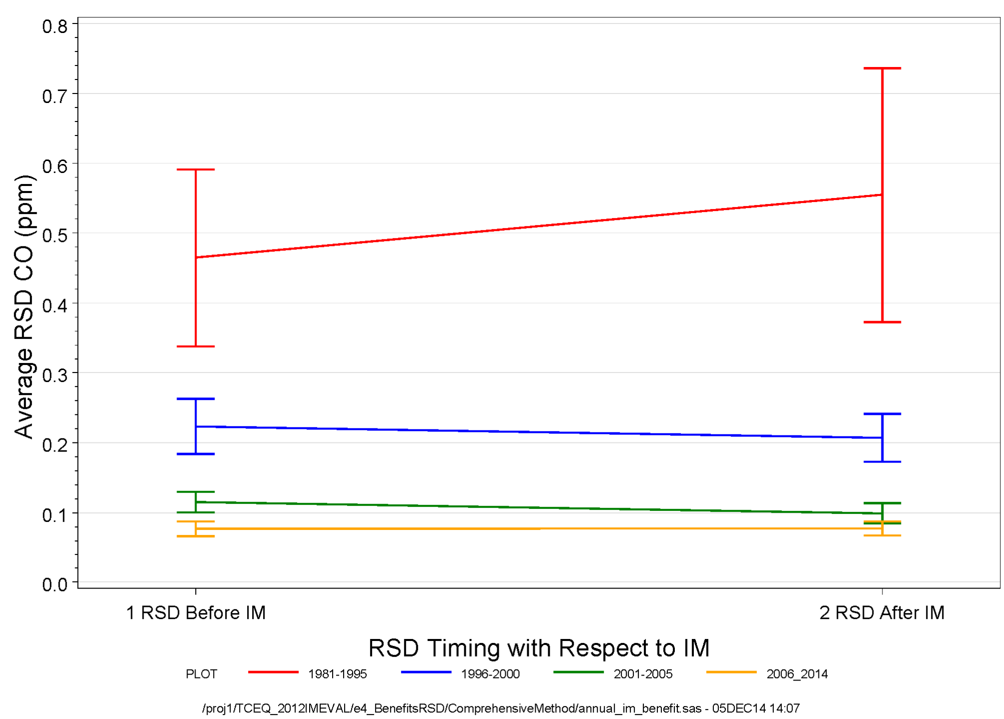
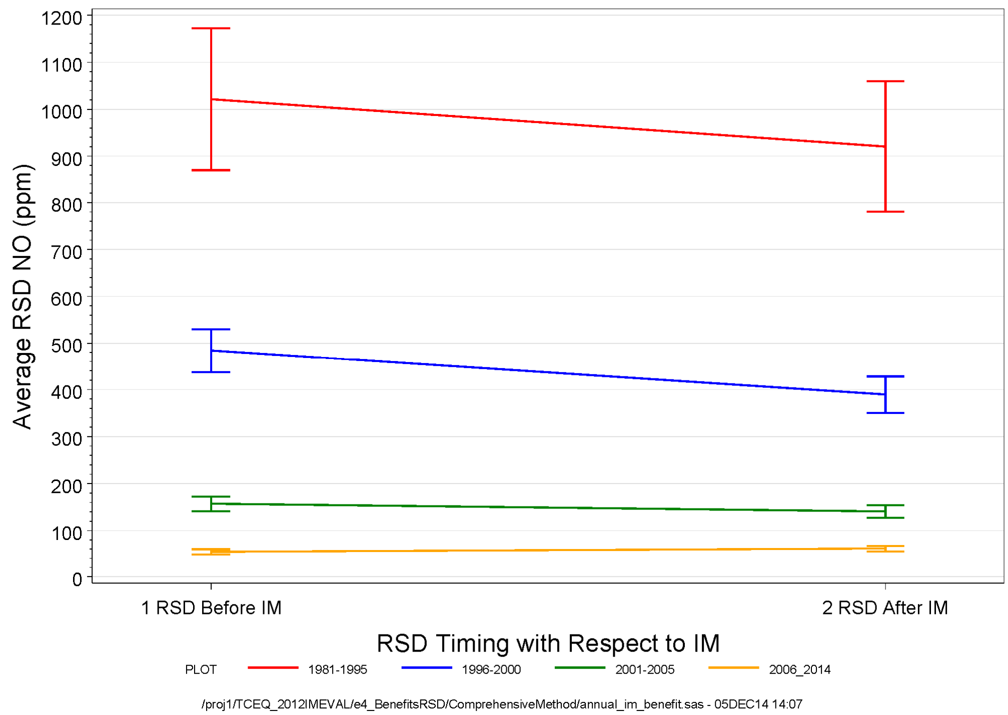


Figure 5-15. Average RS NOx by Model Year Group Before and After I/M Test for AUS Vehicles with I/M Sequence Category = 1P



The RS average concentrations shown in the figures above are summarized in Tables 5-3 and 5-4. The values in Table 5-3 show that for vehicles that failed and then passed, HC and CO emissions were reduced from before to after the I/M inspection, while NOx emissions generally increased. Changes were largest for the oldest model year groups. The counts for vehicles in each model year group are also given; it can be seen that the emissions averages are based on a very small number of vehicles. Table 5-4 shows that for 1P vehicles, changes were smaller from before to after the I/M inspection. However, looking back at Figures 5-10 through 5-15, it can be seen that the changes are almost always within the errors bars, and therefore, not statistically significant.

Table 5-3. RS Averages Before and After an I/M Test for AUS for I/M Sequence Category = FP

	Vehicle Counts		RS HC (ppm)		RS CO (%)		RS NOx (ppm)	
MY Group	**Before I/M**	**After I/M**	**Before I/M**	**After I/M**	**Before I/M**	**After I/M**	**Before I/M**	**After I/M**
1981-1995	19	7	341	120	1.60	0.34	1463	2293
1996-2000	56	56	32	41	0.27	0.30	390	484
2001-2005	109	69	27	14	0.16	0.14	268	178
2006-2014	50	47	5	14	0.16	0.06	72	111

Table 5-4. RS Averages Before and After an I/M Test for AUS for I/M Sequence Category = 1P

	Vehicle Counts		RS HC (ppm)		RS CO (%)		RS NOx (ppm)	
MY Group	Before I/M	Before I/M	Before I/M	After I/M	Before I/M	After I/M	Before I/M	After I/M
1981-1995	148	164	91	105	0.46	0.55	1021	920
1996-2000	714	611	30	35	0.22	0.21	484	389
2001-2005	1866	1733	13	13	0.12	0.10	157	140
2006-2014	2939	2515	10	9	0.08	0.08	53	60

The results in Tables 5-3 and 5-4 show the difference in average RS concentrations between before and after I/M observations, for different model year groups. To calculate the net overall effect on emissions of the I/M program, these results must be combined. Because RS measurements are primarily taken on freeway on-ramps, the average vehicle that is observed by RS is somewhat newer that the average vehicle in the I/M fleet. This difference is shown in Table 5-5, which contains the distribution of vehicles among the model year groups for the RS measurements -matched-to-I/M fleet, and for the I/M fleet. The fact that this difference exists, i.e. that the RS measurements -matched-to-I/M fleet is somewhat newer than the I/M fleet, should be kept in mind when considering overall fleet results.

Table 5-5. Model Year Distributions for RS-Matched-to-I/M Fleet and I/M Tested Fleet

Model Year Group	RS-Matched-to-I/M Fleet		I/M Tested Fleet	
	Number	%	Number	%
1981-1995	1,354	2.8%	69,721	4.6%
1996-2000	5,881	12.1%	216,989	14.3%
2001-2005	16,176	33.3%	499,790	32.8%
2006-2014	25,150	51.8%	735,308	48.3%
Total	48,561	100.0%	1,521,808	100.0%

The overall fleet results for the annual I/M benefit are shown in Table 5-6. The first block of data shows a very slight increase in the RS averages from before to after an I/M test for the entire RS matched I/M fleet for HC, and decreases for CO and NOx. However, as discussed above, the RS averages do drop even for HC for the vehicles that do actually receive a failing test and then a repair to pass the final I/M test. This suggests that the I/M program is causing an I/M benefit for those vehicles even though the emissions do not drop for the entire dataset. It is very possible that in the absence of the I/M program, annual fleet emissions would increase by much larger amounts.

Table 5-6. RS Average Concentrations to Evaluate the Annual I/M Benefit

I/M Sequence Category	RS wrt IM	Number of Obs	RS HC (ppm)				RS CO (%)				RS NOx (ppm)			
			Mean	Upper CLM	Lower CLM	Change (%)	Mean	Upper CLM	Lower CLM	Change (%)	Mean	Upper CLM	Lower CLM	Change (%)
1P + FP	Before	5,903	17	19	15		0.13	0.14	0.12		174	185	163	
	After	5,203	17	19	15	0.5%	0.12	0.13	0.11	-5.6%	162	172	152	-6.8%
1P	Before	5,667	16	18	14		0.12	0.13	0.11		167	177	156	
	After	5,023	17	19	15	6.8%	0.12	0.13	0.11	-1.6%	156	166	146	-6.4%
FP	Before	234	49	77	22		0.30	0.40	0.20		353	432	273	
	After	179	27	35	19	-46.1%	0.18	0.24	0.11	-40.8%	339	433	245	-3.9%

The figures and tables above use RS records that have been paired with IM records, and then categorized by the timing between the RS event and the IM event, as well as the vehicle's IM result sequence. While this is a useful way of looking for the IM "sawtooth" pattern, it does result in smaller groups of records and therefore noisier results. Therefore, the RS data was also used with a much simpler approach: mean emissions for each calendar year, for each of four broad vehicle-age groups. The four age groups were assigned as:

1) OBD vehicles between 0 and 4 years of age (little affected by an IM program),

2) OBD vehicles between 5 and 10 years of age,

3) OBD vehicles greater than 10 years of age, and

4) TSI or ASM vehicles (1995 and older vehicles).

The results are shown in Figures 5-16 through 5-24. Figures 5-16 through 5-18 give results for RS HC means, for each of the three IM areas (HGB, DFW, and AUS). Figures 5-19 through 5-24 give similar results for CO and NOx.

For the HC plots, we see that the four age groups have very different mean emissions. We also see that for each of the age groups, emissions changed slightly from year to year, but without much of a directional trend. However, for the CO and NOx plots, we often see that emissions were highest in 2009 and 2010, and then lower for the more recent years.

Figure 5-16. Mean RS HC by Year and Age Group, for AUS Program

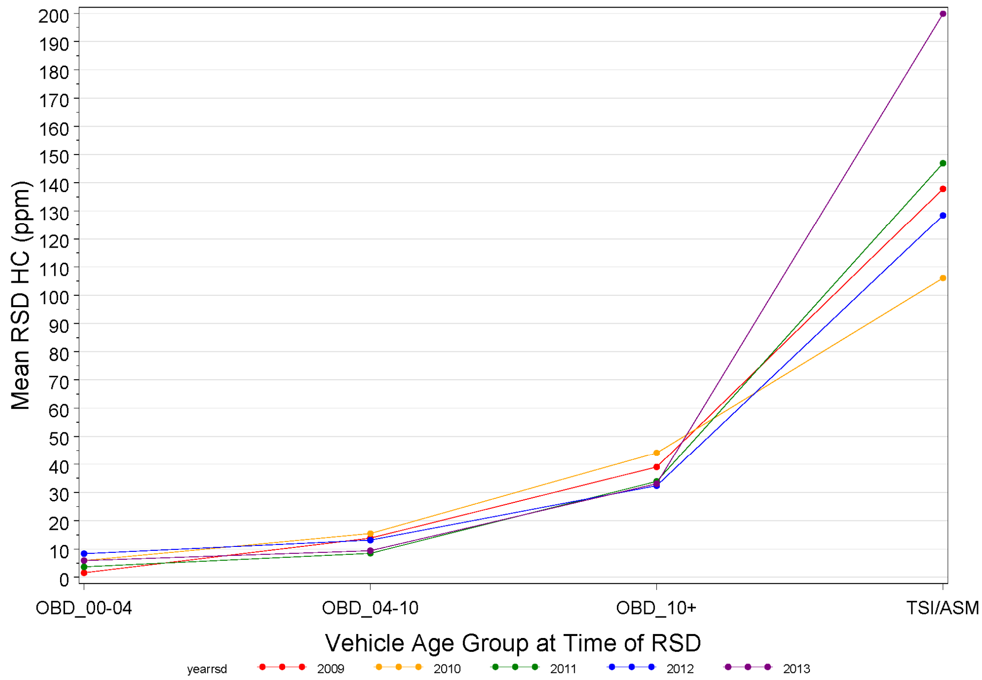


Figure 5-17. Mean RS HC by Year and Age Group, for DFW Program

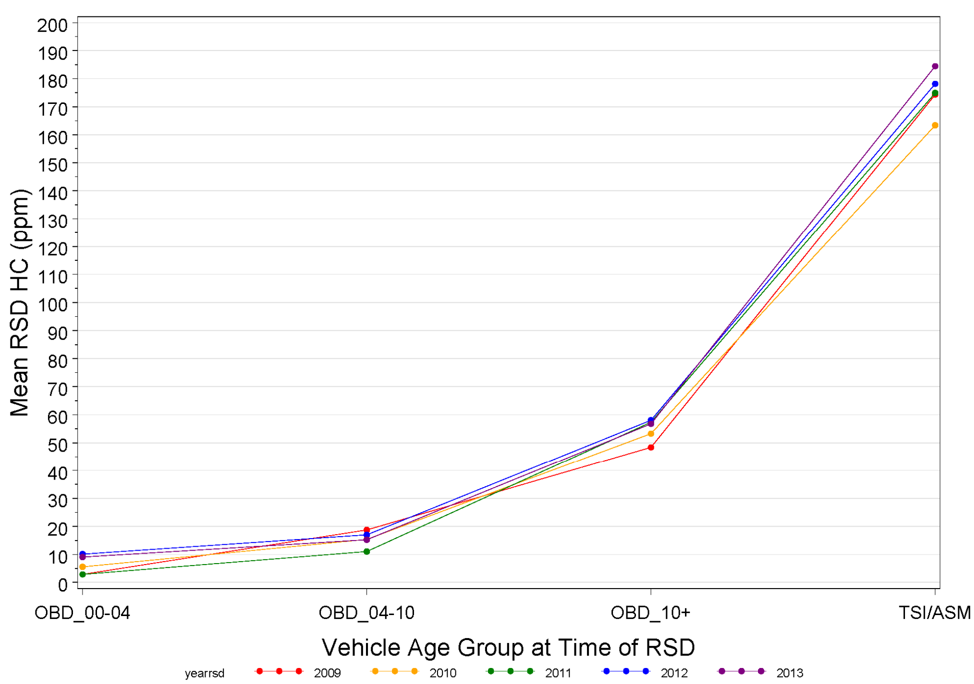


Figure 5-18. Mean RS HC by Year and Age Group, for HGB Program

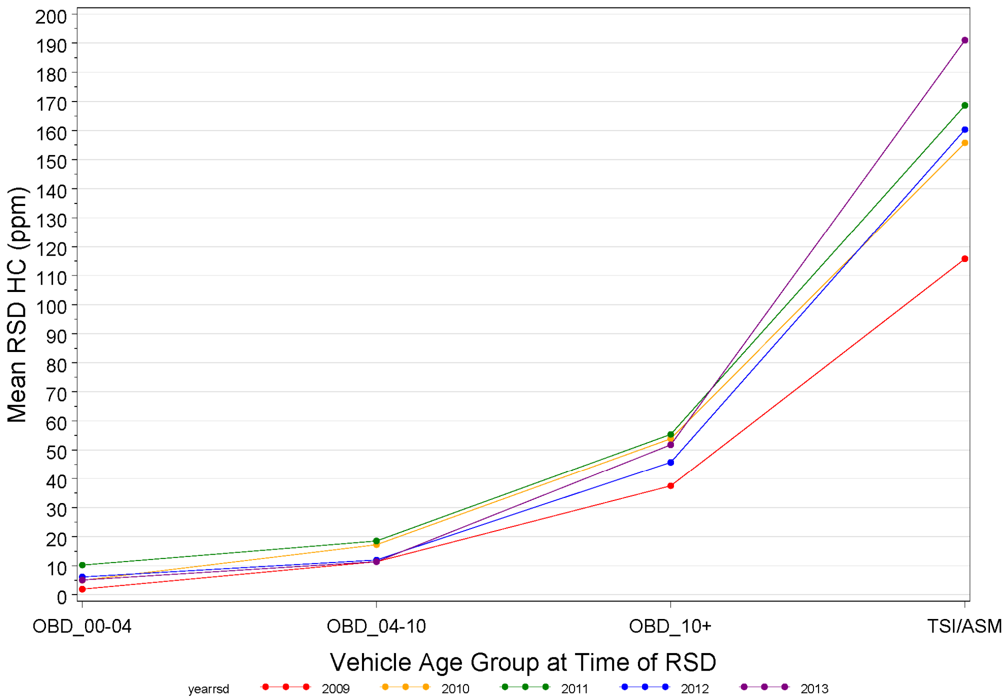


Figure 5-19. Mean RS CO by Year and Age Group, for AUS Program

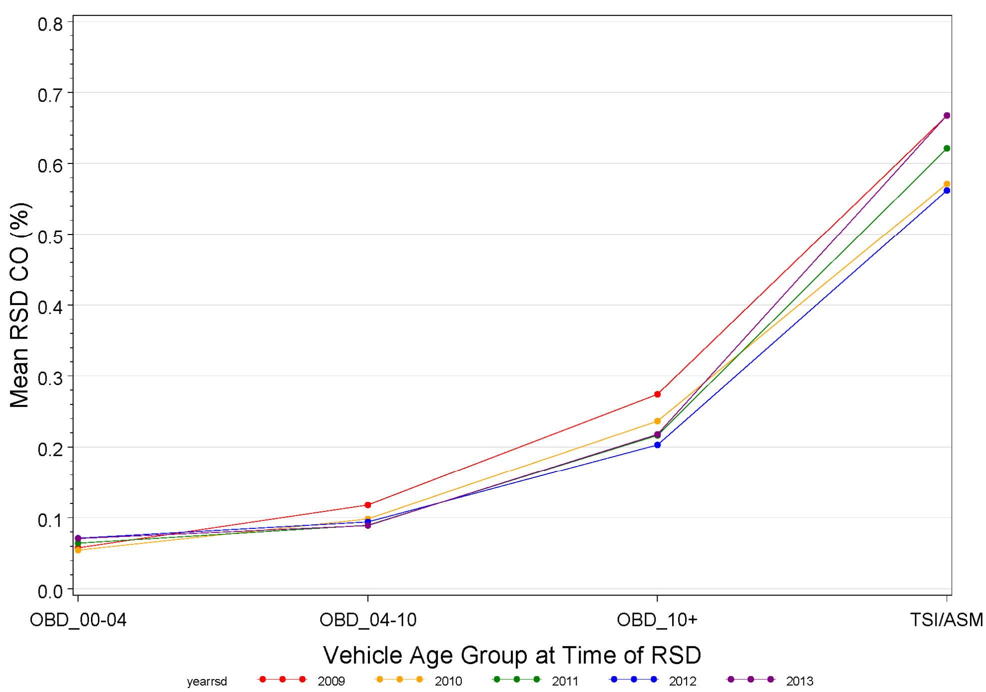


Figure 5-20. Mean RS CO by Year and Age Group, for DFW Program

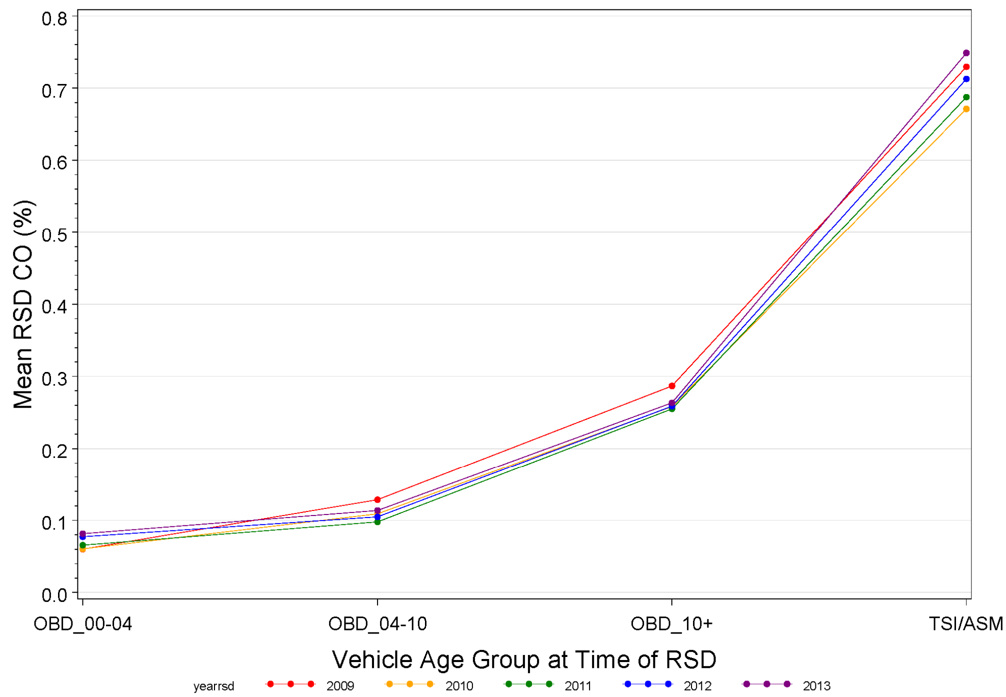


Figure 5-21. Mean RS CO by Year and Age Group, for HGB Program

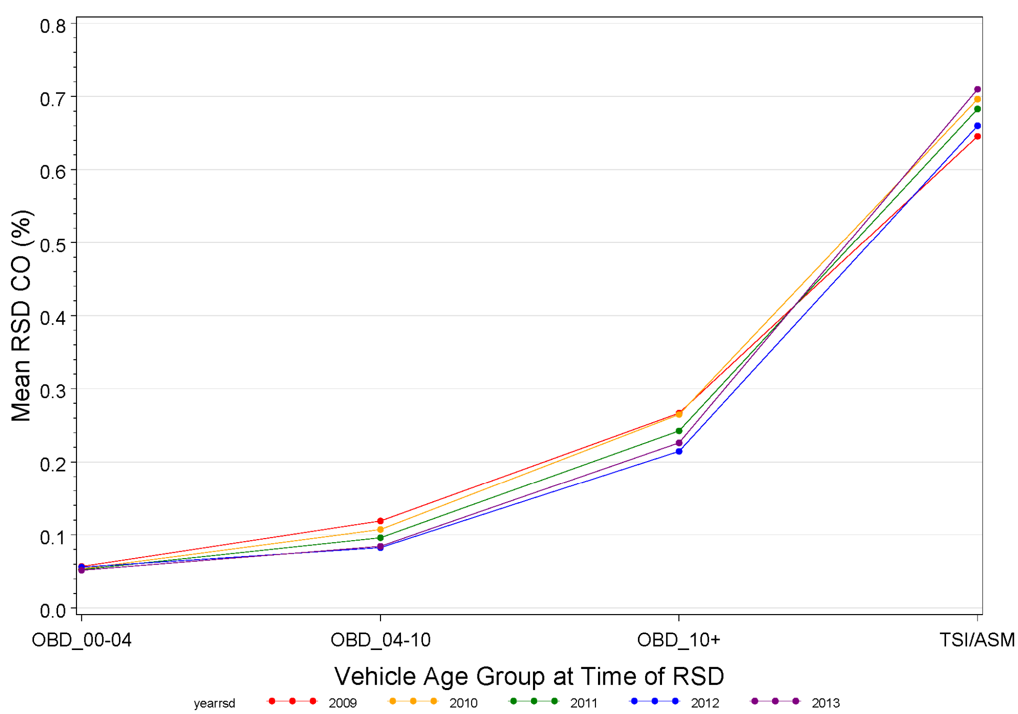


Figure 5-22. Mean RS NOx by Year and Age Group, for AUS Program

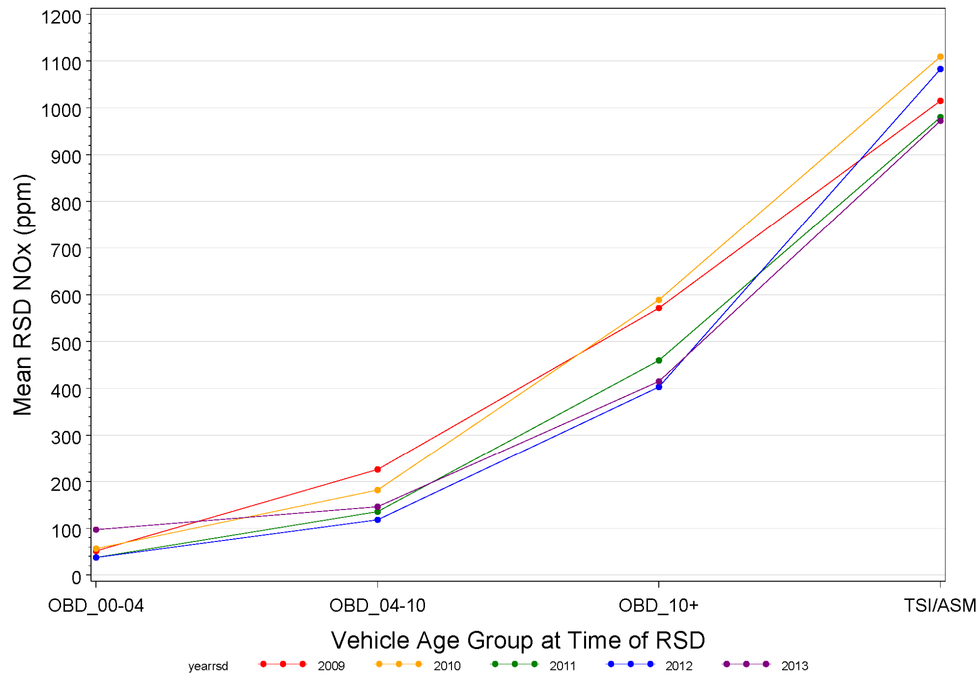


Figure 5-23. Mean RS NOx by Year and Age Group, for DFW Program

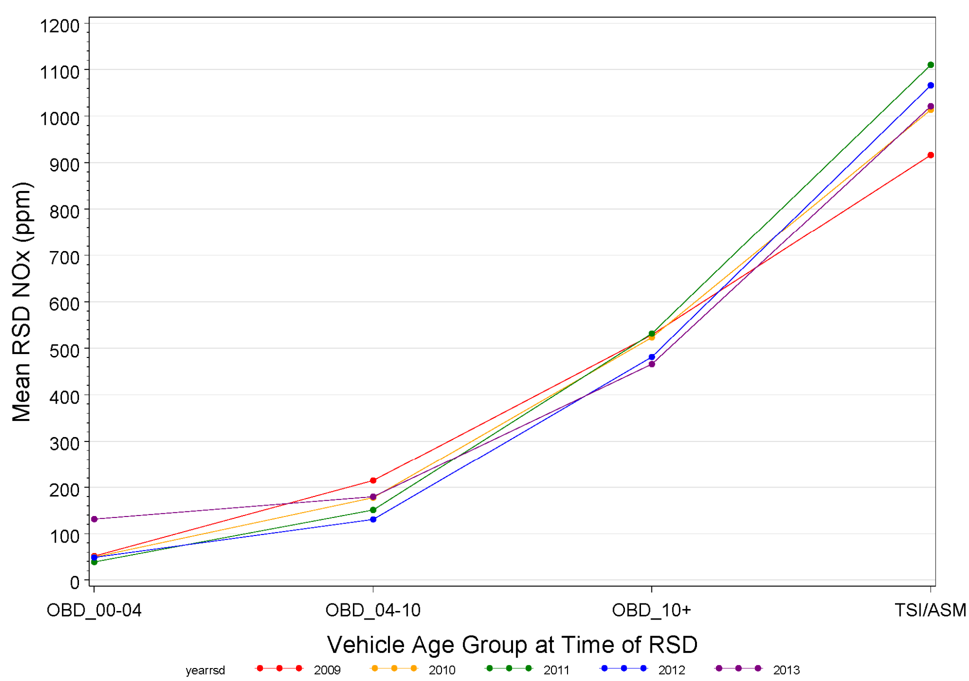
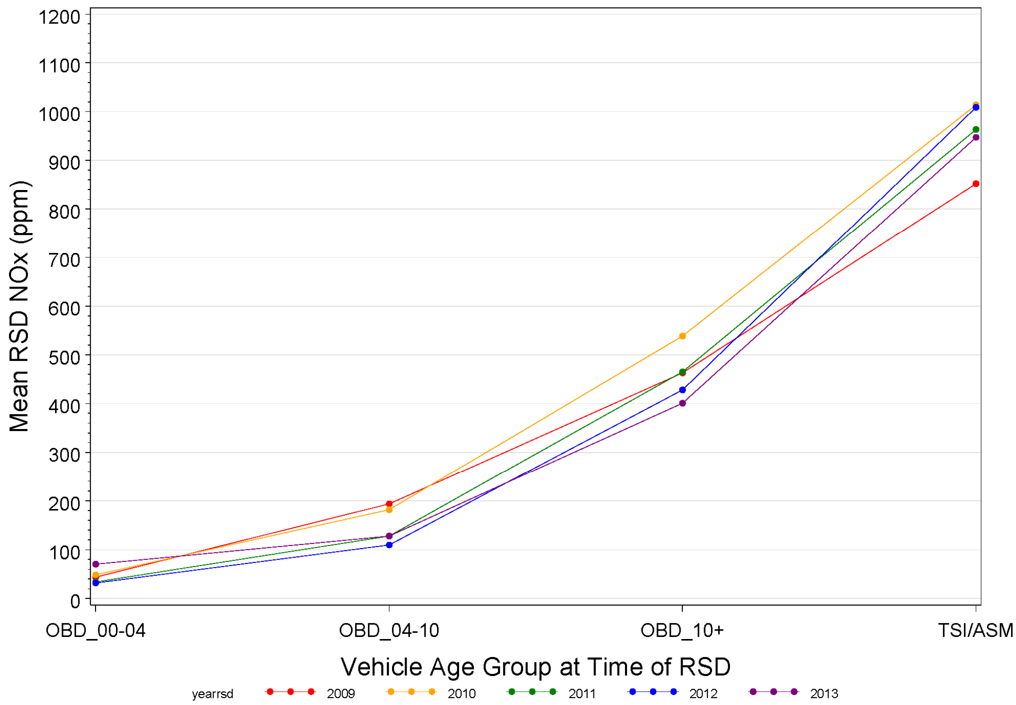


Figure 5-24. Mean RS NOx by Year and Age Group, for HGB Program



6.0 Measures for Evaluating Station Performance

For an I/M program to function as designed, it is critical that each I/M inspection station follow the procedures and regulations that have been created to ensure that inspections are consistently performed properly. In this section, data from the TIMS database are used to explore a range of ways in which individual I/M stations and inspectors may be circumventing procedures or regulations – in other words, cheating. The offenses can be broken into two different levels: 1) errors of commission: intentional breaking of rules to manipulate inspection results, and 2) errors of omission: failure to routinely follow regulated procedures. The specific actions that will be investigated here include:

- Errors of Commission:
  - OBD Fraud Checks (Section 6.1)
    - VIN from vehicle doesn't match OBD-downloaded VIN (6.1.1)
    - Powertrain Control Module (PCM), Parameter ID (PID), VIN, and/or readiness status changes between inspections (6.1.2)
  - Tailpipe Inspection Manipulation (Section 6.2)
    - Clean-piping: a passing retest follows a failed inspection within only a few minutes (6.2.1)
    - Switching vehicle from ASM to TSI in order to pass inspection (6.2.2). This is not applicable to the Austin program because there is no ASM testing.
    - Switching from LD (<8,500 GVWR) to HD (>8,500 GVWR) in order to pass inspection (6.2.3)
    - Stations with a very high or very low fail rates (6.2.4)
- Errors of Omission:
  - Use of analyzers of less-than-optimal functionality (Section 6.3)
- Performing inspections on analyzers with a high degree of drift (6.3.1)
- Performing inspections right before failing a span gas audit (6.3.2)
- Performing only one of the four calibrations that are required every 72-hours, instead of all four (6.3.3)
  - Data entry issues (Section 6.4)
- Consistently entering repair type as "Misc" (6.4.1)
- Consistently entering repair cost as $0 (6.4.2)

- VIN Check digit errors (6.4.3)
- Anomalous inspection sequences (other than 1P or FP) (6.4.4)

— Anomalous test results (Section 6.5)

- Inspection results with greater than 16% CO_2 (6.5.1)
- Inspection results with greater than 20.5% O_2 (6.5.2)
- Inspections with high DCF values (6.5.3)

Obviously, many stations will have the occasional inspection where the analyzer had drifted just before a calibration, or the VIN was accidentally entered incorrectly and didn't match the downloaded OBD VIN, etc. However, the goal of this section is to identify those stations where these events are frequent, suggesting that their occurrence is not accidental and these events are much more common than at other stations.

A percentile rank was assigned to each station for its performance on each bullet the above list. Using a ranking of the stations for each measure permits the comparison of one measure to another measure even if the two have different types of results. The final results were a compilation of the ranks for each station on each of the measures of errors of commission and each of the measures of omission. These compiled ranks are discussed in Section 6.6.

A short list of inspection stations that are operated by the state was provided by the DPS. These stations were excluded from all of the analysis in this section, as they tended to exhibit a substantially different range of results than the majority of stations, skewing the distribution of the results. These stations were: 1G25792, 4G25799, 2G34721, 1G34843, 6G20541, 6G36011, and 2G25739.

6.1 OBD Data Checks for Evidence of Station Fraud

"Clean-piping" is a term used to describe a type of vehicle emissions test fraud in which an inspector substitutes a vehicle with passing emission rates in place of a vehicle with high emission rates in order to achieve a pass record for the high-emitting vehicle. Historically, this has been identified through the use of covert audits, notifications by motorists, and analysis of vehicle emission result trends. For a vehicle receiving an OBD inspection, the analogous practice is typically referred to as "clean-scanning," where a vehicle with no MIL illumination is substituted in place of a vehicle with MIL illumination and stored DTCs in an attempt to receive a passing test result. Although identification of emission results trends is not possible with OBD tests, information downloaded from the OBD system during an inspection may be used to identify possible clean-scanning activities.

6.1.1 Comparison of Inspector-Entered VIN to Vehicle-Downloaded OBD VIN

For OBD vehicles, a comparison of the inspector-entered VIN against the vehicle-downloaded VIN via the OBD connection can help verify that all OBD inspections are performed on the correct vehicle. Both the inspector-entered VIN and the vehicle-downloaded VIN are recorded in each vehicle inspection record of the Texas TIMS.

For this analysis, all test records where no OBD VIN was present were excluded. This reduced the dataset from 1,819,673 records to 1,256,835 records. For each of these remaining records, the OBD-downloaded VINs were compared with VINs entered (either via keyboard or barcode scan) during the vehicle inspection. Approximately 0.8% of these records (9,533 records) were found to have VIN to VIN discrepancies. Manual investigation of these records showed a number of the OBD VINs or entered VINs were invalid (for example, the VINs were less than 17 characters in length, or contained characters that are not allowed in a VIN), and some mismatches were also due to VIN errors in the vehicle test record. An investigation of the VIN discrepancies, shown in Table 6-1, revealed that vehicles from the early years of OBD (1996-1999) had very high rates of discrepancies, with as many as 60% of vehicle records containing a discrepancy. Rates were very low for the later model years, in part due to federal requirements for the OBD system to provide the OBD VIN on model year 2005 and newer vehicles. However, it should be noted that the vehicles that benefit from clean-scanning are those that fail an inspection and that group would likely be dominated by the early model-year vehicles, rather than the newer vehicles.

These results for Austin are lower than those reported for DFW/HGB, with 1.4% of records showing a VIN mismatch, and with lower rates in Table 6-1 for Austin than in the corresponding table for DFW/HGB.

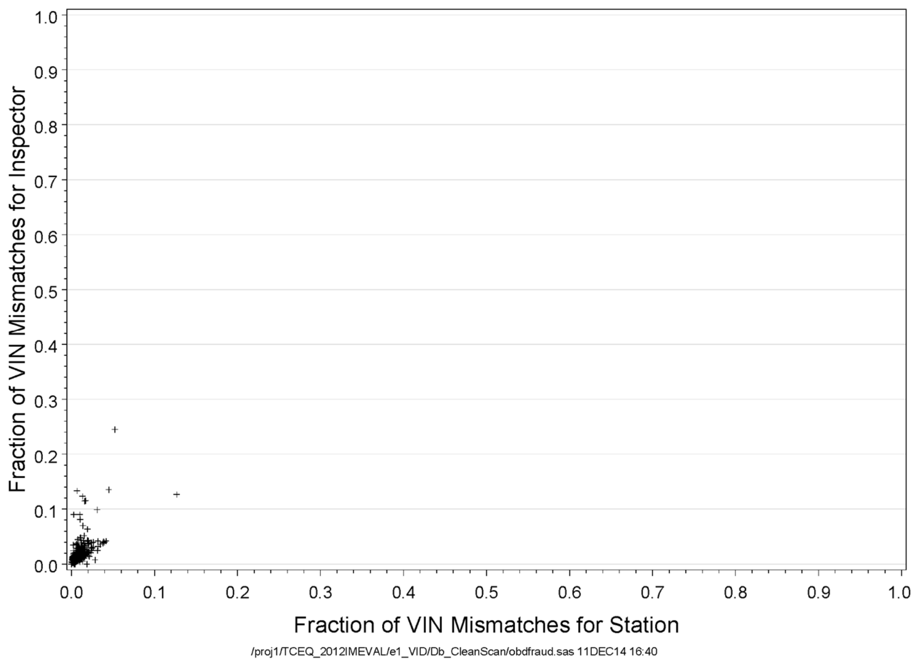
Table 6-1. Rates of OBD-Downloaded and Inspector-Entered VIN Discrepancies, by Model Year

Model Year	Number of OBD Inspections with VIN Mismatch	Percent of OBD Inspections with VIN Mismatch	Total Inspections
1996	66	60.6%	109
1997	104	57.8%	180
1998	108	57.8%	187
1999	220	45.3%	486
2000	795	6.9%	11,516
2001	979	2.2%	44,144
2002	1,129	2.1%	53,302
2003	1,304	2.0%	63,875
2004	1,606	2.0%	80,967
2005	913	0.6%	145,856
2006	587	0.4%	156,610

Model Year	Number of OBD Inspections with VIN Mismatch	Percent of OBD Inspections with VIN Mismatch	Total Inspections
2007	513	0.3%	173,213
2008	399	0.2%	167,702
2009	253	0.2%	111,403
2010	285	0.2%	128,339
2011	184	0.2%	86,994
2012	80	0.3%	27,898
2013	8	0.2%	4,054

The rate at which VIN discrepancies were recorded was calculated for each station that performed OBD inspections, and for each inspector. These are compared graphically in Figure 6-1. The horizontal axis shows the fraction of OBD inspections that contained a VIN discrepancy for each station, while the vertical axis shows the fraction of OBD inspections with a VIN discrepancy for each inspector. To reduce errors due to small sample size, stations or inspectors that performed fewer than 100 inspections were excluded from the plot. The large cluster of points at the bottom left corner of the plot includes most stations and inspections. This cluster pattern indicates that these stations and inspections had a near-zero rate of VIN discrepancies. The points closer to 1 on the horizontal or vertical axis indicate stations or inspectors that almost always produced OBD records with a VIN discrepancy. These very-high rates could in part result from practices other than clean-scanning, such as sloppy data entry when the VIN is manually entered, or vehicles with an invalid OBD VIN (earlier model years or PCM replacements).

Figure 6-1. Rates of OBD-Downloaded and Inspector-Entered VIN Discrepancies, by Station and Inspector



One additional factor that was calculated for each station was the number of times the same VIN was downloaded in different OBD inspections. If clean-scanning is taking place, there is a good chance that the “clean” vehicle would be used repeatedly and its VIN would be downloaded numerous times, whereas VIN typos would vary with each inspection. When this was done for the DFW and HGB areas, it turned out to be a revealing investigation, as it was found that some stations did OBD inspections on the same downloaded-VIN hundreds of times. However, this was not found to be the case in the Austin area: the highest number of inspections by one station on one downloaded VIN was only 27.

These VIN mismatch findings were condensed into a rank for each station, based on the fraction of inspections that revealed a disagreement between the entered VIN and the downloaded VIN. Stations that performed fewer than 100 OBD inspections over the two year period were again excluded from the results, due to the possibility of spurious results from the small sample size. As an example of the findings, the VIN mismatch rates for the 10 worst offending stations are listed below in Table 6-2. The table shows the rate at which there was a disagreement between the entered VIN and the downloaded OBD VIN, out of all inspections at that station that included a 17-digit VIN in both fields. The table also shows the maximum number of times a single VIN was tested at each station. These rates are far lower than those found for the worst stations in the HGB and DFW areas.

Table 6-2. Stations with Highest Rates of OBD and Entered VIN Mismatches

Station ID	Percent of Inspections Where VIN Did Not Match	Total Number of Inspections Performed at Station	Maximum Number of Tests on a Single VIN	Percentile Rank for Station
Ten worst stations:				
6P40485	12.7	583	4	100.0
6P38785	5.2	1032	27	99.8
6P39239	4.5	1155	15	99.6
6P39028	4.2	215	4	99.3
6F31011	4.0	100	3	99.1
6P39876	3.8	287	4	98.9
6P42293	3.8	157	4	98.7
6P44900	3.5	173	3	98.5
6P16528	3.2	1123	5	98.3
6P41917	3.2	726	7	98.0

6.1.2 Comparison of Vehicle-Specific Information between the First Test and Subsequent Tests

The purpose of this analysis was to compare OBD-downloaded information for a given vehicle on its first inspection, to OBD-downloaded information on retests of that same vehicle. Certain types of OBD information may be combined to create unique "electronic profiles" for each vehicle, and the electronic profile should be the same at the initial inspection and at subsequent inspections. If the electronic profile changes from one inspection to the next, inspection fraud may be suspected. For this analysis, only those vehicle inspection cycles that included an initial test and at least one retest were used, and only records where monitor readiness values were non-missing were used, reducing the dataset from 1,819,673 OBD inspections to 292,286 inspections. This includes 138,893 initial inspections, and 153,393 retests.

Three variables were used to create the first "electronic profile" for each vehicle: the OBD-downloaded VIN, the PCM ID, and the PID Count. The downloaded values for these three variables from all OBD tests conducted over the two-year audit period are summarized below:

- OBD VIN: OBD-downloaded VINs (valid or invalid) were only available in 56% of the test records. The OBD VIN or the manually entered VIN was null in the remaining 44% of the OBD test records. Because of this, use of the OBD VIN in itself would not be sufficient to positively identify clean-scanning.
- PCM Module ID: PCM Module ID was available in all of the test records. 40 unique PCM Module IDs were seen, but 57% of all PCM Module IDs had a value of "10". One other PCM Module ID represented another 21% of records, two other PCM Module IDs each comprised an additional 2 to 4%

of the test records, and the remaining test records were distributed among the other 36 PCM Module IDs. Because of this, as with the OBD VIN, use of PCM Module ID alone would not be sufficient to positively identify clean-scanning (a substituted vehicle could easily have a value of "10" or one of the other common PCM Module IDs).

- PID Count: 86 unique PID Count values were seen, and all but 2 OBD test records contained a value for PID Count. Seven PID Count values were seen in 68% of all OBD test records, while the remaining test records contained one of the remaining 79 PID Count values.

- When the PCM Module ID and PID Count are looked at in combination, the three most common combinations comprise 15, 10, and 7% of inspections, with 432 combinations making up the remainder of inspections. Thus the combination of PCM Module ID and PID Count actually is highly variable and may be a good indicator of a different vehicle being substituted for the test.

The second electronic profile that was created was an "enabled profile". For this, OBD monitors were identified that are commonly found to be both "monitored" and "not monitored," depending on the make/model/model year of vehicle being inspected. For example, very few vehicles have monitored positive crankcase ventilation or air conditioning systems, so these would be poor indicators of potential clean-scanning since the monitored status is almost surely the same for two different vehicles. Similarly, catalysts and oxygen sensors are almost always monitored, so these too would be poor indicators of potential clean-scanning. Again, two different vehicles will likely both have these monitored. As shown below, EGR systems, evaporative systems, and to a lesser extent heated oxygen sensor systems and secondary air injection systems were seen to have significant percentages of vehicles with both "monitored" and "not monitored" status:

- EGR systems: 45% not monitored, 55% monitored

- Evaporative systems: 6% not monitored, 94% monitored

- heated O_2 systems: 3% not monitored, 97% monitored

- secondary air systems: 93% not monitored, 7% monitored

- When the status of the four monitors is looked at together, two combinations of monitor status dominated the dataset, with 49% and 35% of vehicles. Smaller numbers of vehicles comprised the remaining 14 combinations and 16% of vehicles. Since the combined monitored status of these four monitors could provide a distinguishing and characteristic profile from vehicle to vehicle, these four monitors were used for this analysis.

An electronic profile and a monitored-status profile were created for each vehicle, for its initial inspection and for any re-inspections. Any tests where either profile differed from inspection to inspection were flagged. Tests where both the electronic profile and the monitored-status profiles changed would be an indicator that a different vehicle was being substituted for the test. Note that for any individual vehicle, these downloaded values may vary among analyzer manufacturers (in particular the PCM Module ID and the PID Count), so the analysis was based on vehicle/analyzer combinations. All inspections where the initial inspection took place on a different type of analyzer than that used for the retest inspection were excluded from the analysis.

Occasionally, analyzer hardware upgrades or software updates could result in OBD system PID count mismatches between multiple tests on the same vehicle, and the OBD-downloaded VIN could be mismatched on multiple tests from the same vehicle in extremely rare instances where the PCM on the vehicle was improperly reprogrammed in an attempt to repair the vehicle. An assessment of the likelihood of fraud is provided for each of the scenarios listed below. It is also worthwhile to note that since each vehicle's OBD system "profile" was assigned based on the information collected during the vehicle's first test, this analysis would not identify any tests where a vehicle was substituted, i.e., clean-scanned, during the initial inspection.

As described above, the dataset included 138,893 initial inspections and 153,393 retests. Of those retests, 14,000 took place on a different type of analyzer than that of the initial test, and were excluded from the results. This left 139,867 retests for analysis. The results of the analysis were:

- 137,089 (98% of the 139,867-record dataset) tests had matches for both the electronic profile and the readiness profile between initial test and subsequent retests on the same analyzer. These tests very likely indicate compliant testing.

- 480 (0.3% of the 139,867 record dataset) tests had a mismatch for both the electronic profile info and the readiness profile, between the initial test and at least one retest on the same analyzer. Test pairs where both computer ID information and readiness profile differ are likely to be performed on two different vehicles (i.e., an indication of clean-scanning).

- 2,343 (1.7% of the 139,867 record dataset) tests had an electronic profile mismatch info between the initial test and at least one retest on the same analyzer, but the "readiness profile" matched between the initial test and all subsequent retests on the same analyzer. Since the computer ID serves as a unique identifier for any vehicle, this information should always match for retests on the same vehicle. A mismatch could occur only in the following scenarios:

— if another vehicle was substituted for a retest (clean-scanning)

— if an anomaly in the analyzer software interpreted the computer ID info two different ways on subsequent retests for the same vehicle

— if a vehicle repair was performed in which the vehicle's PCM was re-programmed with new ID info as a part of a repair

Although the last two scenarios are unlikely, it was not possible to quantify the likelihood of this occurring in this analysis. It is possible for two different vehicles to have common readiness profiles, so a readiness profile match does not confirm that clean-scanning did not occur. Therefore, this scenario (computer ID mismatch) is felt to be a good indicator of clean-scanning.

- 35 (0.03% of the 139,867 record dataset) tests had a "readiness profile" mismatch between the initial test and at least one retest on the same analyzer, but the electronic profile matched between the initial test and all subsequent retests on the same analyzer. This scenario is difficult to interpret, since the readiness profile is based on "monitored vs. unmonitored" status of various systems, as opposed to ready/not ready status, and therefore should never change for a vehicle despite the vehicle's state of readiness. Similarly, the computer ID information should be static for any one vehicle except for the case when PCM reprogramming is part of the repair process. Because of the contradictory results, the scenario of a readiness profile mismatch with a computer ID info match is not considered to be a strong indicator of non-compliant testing.

A summary of this information is provided in Table 6-3. These rates are considerably lower than those reported in the corresponding table for DFW/HGB.

Table 6-3. Percentages of Tests with Various OBD Fraud Indicators

Retest Match Scenario	Retest-only Dataset (139,867 tests total)
All match (compliant)	98 %
Readiness mismatch (ambiguous)	0.03 %
PCM ID info mismatch (fraud likely)	1.7 %
Both mismatch (fraud very likely)	0.3 %
Estimated % of clean-scanning	1% to 2%

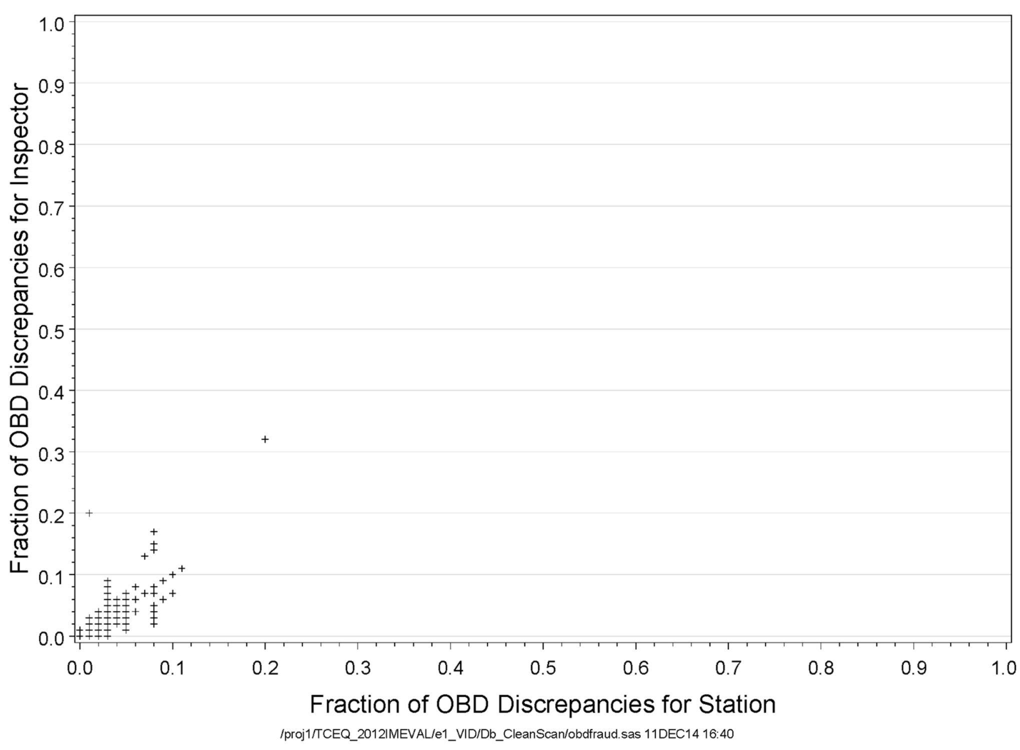
Next, using the complete dataset, which includes tests classified as initial tests, the following general statistics were seen for stations and inspectors with computer ID information or "readiness profile" mismatches.

- Over the two-year audit period, 72% of the 486 inspection stations had at least one test record with either a readiness profile or computer ID information mismatch between an initial test and a subsequent test for the same vehicle (tested using the same analyzer as the initial test). The maximum number of mismatch retest records for any one station was 111 records over the two-year period. All remaining stations had less than 100 records with a mismatch. Station mismatch rates as high as 20% were seen.

- Over the two-year audit period, 24% of the 4.024 inspectors had at least one test record with either a readiness profile or computer ID information mismatch between an initial test and a subsequent test on the same vehicle using the same analyzer. The maximum number of mismatch retest records for any one inspector was 82 records over the two-year period. Inspector mismatch rates as high as 32% were seen.

The distribution of station and inspector mismatch rates is shown in Figure 6-2. The horizontal axis shows the fraction of retest records that contained an electronic profile or readiness profile mismatch, for each station. The vertical axis shows the fraction for each inspector. The large concentration of data points in the lower left corner are stations and inspectors that produced retest records that rarely had a mismatch when compared to the information from the initial inspection. In contrast, the stations/inspectors in the upper right-hand portion of the chart are those that are most likely to be clean-scanning.

Figure 6-2. Rates of Re-Test Discrepancies in OBD Computer and Readiness Information, by Station and Inspector



These results were condensed into a rank for each station, based on the fraction of retest inspections performed at that station that included both an electronic profile mismatch and a readiness profile mismatch. Stations with fewer than 100 OBD retest inspections over the two year period were excluded from the results, due to the possibility of spurious results from the small sample size. The 10 stations with the highest rates of profile mismatches are listed in Table 6-4. Some electronic profile and/or readiness mismatches are to be expected, and as mentioned above, more than 72% of stations had at least one case of a mismatch. However, most of those stations had only one or a few mismatches. Overall, about 0.3% of retest inspections resulted in a readiness profile and electronic profile mismatch. When stations with a mismatch in as many as 15% of their inspections are seen, one can start to suspect that something beyond the expected occasional difference is taking place.

Table 6-4. Stations with Highest Percents of Electronic Profile and Readiness Profile Mismatches

Station ID	Percent of Re-inspections with BOTH Electronic & Readiness Mismatch	Number of Re-inspections at Station	Percentile Rank for Station
Ten worst stations:			
6P32530	15.0	187	100.0
6P39560	11.5	104	99.7
6P16087	10.5	152	99.3
6P39239	6.3	254	99.0
6P41789	4.3	322	98.6
6P40868	4.2	168	98.3
6P38126	4.0	225	97.9
6P16528	3.1	259	97.6
6P39448	2.9	1075	97.3
6P39846	2.9	418	96.9

6.2 Tailpipe Inspection Data Checks for Fraud

Unlike OBD inspections, tailpipe emissions inspections do not include the download of vehicle-specific information that remains unchanged from an initial inspection to a re-inspection. However, several different types of inspection results have been identified that may provide good indicators that tailpipe emissions inspection fraud may be occurring at a given station. Several of these are extremely uncommon in the TIMS dataset as a whole, but are relatively common for a handful of stations.

- Sometimes a failing inspection is followed by a passing inspection only a few minutes later. This could indicate the occasional warm-up or easy repair when it happens once or twice for each station, but when it occurs a large number of times at only a few stations, it is more likely to indicate clean-piping.

- Occasionally a vehicle receives an initial inspection that is an ASM test, and a retest inspection that is a TSI test. When such switches occur a large number of times at a single station, and when the test results also show that most of the ASM tests were failed for high NO_x levels (NO_x is not measured in a TSI test), it is likely to indicate a version of inspection fraud. However, since the Austin program uses only the TSI inspection, ASM/TSI switches are not an issue.

- Similarly, an initial failed inspection of a light-duty vehicle (GVWR<8,500 lbs) is sometimes followed by a passed inspection of that vehicle as a heavy-duty vehicle. Cutpoints are higher for HD vehicles, making the inspection easier to pass. This happens very infrequently in the dataset as a whole, but much more frequently at some stations.

- The overall failure rate at a station can be used as an indicator of whether fraud is occurring. Unusually high or unusually low failure rates may both be a cause for concern. This factor can be difficult to analyze, since it is known that different areas with a different type of fleet (or a different socio-economic status) often have real differences in failure rates.

Each of these factors is discussed in more detail in the following sections, and a ranking is assigned to each station, for each factor.

6.2.1 Short Time Interval Between Inspections

For inspection cycles that begin with a failing inspection, a retest (or retests) usually follows a day or several days after the initial failed inspection. Presumably, repairs are performed during that interval between inspections. However, some failing inspections are followed by a passing inspection within minutes, leading one to wonder how the vehicle was successfully repaired so quickly, or if instead clean-piping occurred for the passing retest. The dataset shows that many stations have one or a few cases of a passing retest following a failing initial test within a short time. These occasional cases may be the real result of a simple fix: a reconnection of a loose line or wire or other simple change, or from retesting a vehicle that previously had not been properly warmed-up. Some vehicles which failed with emissions levels very near the cutpoints might also be retested after no repairs, and pass due to the I/M test variability. However, some stations show a much more frequent occurrence of initial inspections being quickly followed by passing inspections when compared to the majority of stations. In these cases, there may be cause for a suspicion of inspection fraud.

For this analysis, any inspections that were aborted or had dilution problems were deleted from the dataset, and only TSI inspections were considered. This left 101,963 observations in the dataset. In addition, only time differences on retest inspections that were conducted at the same inspection station as the initial inspection were used. This resulted in a dataset of about 13,307 retest observations. The number of times that a failed initial inspection was followed by a passing retest within 15 minutes at a given station over a 2 year period was found. It was discovered that in the Austin program, this happened only three times at the station with the highest frequency of occurrences, while for most of other stations that performed tailpipe inspections, it did not ever happen. Therefore, this does not appear to be an avenue for inspection fraud in the Austin area.

The ten stations with the highest rate of close-in-time retests are listed in Table 6-5. The percentage was calculated from the number of close-in-time retests and the total number of retests, at that station. Stations that performed fewer than 100 retest inspections over the 2 year period are excluded from the results.

6.2.2 Changing from ASM to TSI Inspection to Pass

Since the Austin program uses only the TSI inspection, changing the tailpipe inspection type would not be a source of inspection fraud in the Austin area.

6.2.3 Changing Vehicle Type from Light Duty to Heavy Duty to Pass Vehicle

Given that inspection standards are less stringent for heavy-duty vehicles than for light-duty vehicles, ERG investigated whether switching a vehicle from having a light-duty GVWR (less than 8,500 lbs) to a heavy-duty GVWR was ever used to manipulate emissions inspection results. The vehicle GVWR is an inspector-entered field in the inspection record.

For this analysis, any inspections that were aborted or had dilution problems were deleted from the dataset, and OBD and TSI inspections were considered. Only inspection cycles where the initial inspection and the retest inspection were conducted at the same station were used. This left 145,324 OBD and TSI retest inspections in the dataset.

Overall, it was found that less than 0.1% of inspections that were initially failed as a light-duty vehicle were followed by a passing retest as a heavy-duty vehicle. Also, the rate of switching never exceeded 5% for any station, as shown in Table 6-5. The table shows the ten inspection stations with the highest frequency of retests that involved a vehicle that failed as a light-duty vehicle on the initial inspection, followed by a passed retest of the same vehicle as a heavy-duty vehicle. At the first station on the list, 4% of vehicles that failed as a light-duty vehicle were switched to a heavy-duty vehicle, and then passed. This is a lower overall rate and a lower rate for the 109 highest ranked stations, as compared to the corresponding DFW/HGB results.

Table 6-5. Percent of Retest Inspections Switched from Light-Duty to Heavy-Duty, for 10 Highest Ranking Stations

Station ID	Percent of Retests Switched from LD to HD	Number of Switched Retests	Total Number of Retest Inspections	Percentile Rank for Station
6P28318	4.2	12	287	100.0
6P35109	2.0	6	305	99.7
6P41436	1.4	3	217	99.3
6P38133	1.1	7	628	99.0
6P39036	1.1	3	276	98.6
6P36973	1.0	1	100	98.3
6P41953	1.0	1	101	98.0
6P16646	0.9	1	108	97.6
6P32245	0.9	3	337	97.3
6P16158	0.9	1	113	96.9

6.2.4 Pass/Fail Outliers

Stations can also be evaluated based upon the percentage of vehicles that they pass or fail. Extremely high rates of either passing or failing vehicles may warrant further scrutiny by the DPS. Since typical pass/fail rates vary widely among inspection types (OBD, ASM, and TSI), this analysis was done separately for OBD and TSI inspections, resulting in two separate percentile rankings for each station.

It is recognized that differences in inspection failure rates among stations are often due to factors other than fraud. For instance, the age and maintenance level of the fleet tested at each station may vary widely. However, evaluation of the fleet quality and/or socio-economic status of the area each station is beyond the scope of this evaluation, and only overall pass/fail rates for each station are considered here.

Since it was necessary to identify both very low and very high failure rates, the stations were divided into two groups: stations with a failure rate that was above the mean failure rate over all stations, and stations with a failure rate that was below the mean failure rate over all stations. The stations with a failure rate that was above the mean were ranked with the 0% rank for the station at the mean and the 100% rank for the station with the highest failure rate. The stations with a failure rate that was below the mean were ranked with the 0% rank for the station at the mean, and the 100% rank for the station with the lowest failure rate. Thus each station gets one rank, either for being high or being low. The highest failure rate stations are listed in Table 6-6, with failure rates for OBD and TSI inspections listed separately. The lowest failure rate stations are listed in Table 6-7, with failure rates for OBD and TSI inspections listed separately. Stations with fewer than 100 inspections are excluded from the results. The highest failure rates for the Austin stations in Table 6-6 are lower than the corresponding highest failure rates for DFW/HGB stations performing TSI inspections.

Also, the lowest failure rates in Table 6-7 for Austin are not as low as the lowest failure rates that were found for DFW/HGB (there, many stations with zero failure rates were found).

Table 6-6. Stations with Highest Failure Rates, OBD and TSI

Station ID	Failure Rate (%)	Number of Failed Inspections	Total Number of Inspections	Percentile Rank for Station
OBD Inspection Results:				
6P42864	24.4	205	839	100.0
6P16374	22.6	83	368	99.4
6P42293	22.1	58	262	98.9
6P41917	21.9	270	1231	98.3
6P39846	18.8	511	2715	97.7
6P44959	18.5	139	752	97.1
6P38785	17.1	361	2106	96.6
6P16372	17.1	815	4766	96.0
6P39918	16.2	1044	6440	95.4
6P35087	16.2	1183	7304	94.9
TSI Inspection Results:				
6P41917	33.3	48	144	100.0
6P37116	22.8	91	399	99.0
6P40859	22.4	30	134	98.1
6P39448	21.6	55	255	97.1
6P40225	21.0	42	200	96.1
6P40030	19.8	22	111	95.1
6P36799	19.7	71	361	94.2
6P37571	19.6	58	296	93.2
6P39918	19.4	188	969	92.2
6P41385	19.2	20	104	91.3

Table 6-7. Stations with Lowest Failure Rates, OBD and TSI

Station ID	Failure Rate (%)	Number of Failed Inspections	Total Number of Inspections	Percentile Rank for Station
OBD Inspection Results:				
6P35331	0.4	24	6079	100.0
6F16722	0.9	2	216	99.7
6P04783	1.1	20	1774	99.3
6P44439	1.2	20	1709	99.0
6P00484	1.3	12	938	98.6
6P41519	1.3	20	1561	98.3
6P16083	1.3	144	11177	97.9
6P23086	1.3	24	1856	97.6
6P44893	1.5	3	204	97.2
6P16646	1.6	84	5321	96.9
TSI Inspection Results:				
6P35331	0.8	5	609	100.0
6P41022	2.0	2	102	99.2
6P02869	2.0	3	147	98.3
6P31821	2.1	8	375	97.5

Station ID	Failure Rate (%)	Number of Failed Inspections	Total Number of Inspections	Percentile Rank for Station
6P07257	3.3	10	305	96.6
6P37283	3.4	24	703	95.8
6P35044	3.4	7	203	94.9
6P38639	3.5	4	115	94.1
6P23017	3.8	72	1891	93.2
6P28318	3.9	12	308	92.4

6.3 Repeated use of Analyzers with Less-Than-Optimal Functionality

The accuracy of vehicle inspection results and the quality of the data that is stored in the TIMS database depends in part on each analyzer being fully functional at all times. Consistently using an analyzer that is out-of-specification reduces the accuracy of inspection results.

6.3.1 High Degree of Drift

In Section 3.4.1, the impact of analyzer drift was evaluated. Analyzers that consistently drift little from calibration to calibration can be expected to produce more accurate measures of vehicle emissions than those that drift greatly. If the difference between the bottle label value and the pre-calibration analyzer reading is very large, then one presumes that some of the emissions measurements made during the previous 72 hours were more inaccurate than necessary. Here, the percentage of the time that analyzers were found to have drifted out of the specification range prior to the calibration was calculated for each station. Stations with fewer than 40 calibration events in the dataset were excluded from the results. An analyzer was defined as having drifted out of tolerance if any of the gas values (HC, CO, NO_X, CO_2, or O_2) at any level (zero, low, or mid span) were measured to be outside of the specified tolerance at the beginning of the calibration. However, since HC at the zero level was found to be out-of-tolerance in about half of all calibrations, it was not used here because it would not be a useful predictor of poor performance. Using this strict standard, 93% of stations were found to have had at least 1 or more calibrations on initially out-of-tolerance analyzers; however, the worst stations that are shown in Table 6-8 had almost all calibrations on out-of-tolerance analyzers. This is similar to the result that was found for DFW/HGB stations.

Table 6-8. Percent of Calibrations that Began with an Out-of-Tolerance Analyzer

Station ID	Analyzer ID	Percent of Calibrations that Began with Out-of-Tolerance Analyzer	Number of Calibrations that Began Out-of-Tolerance	Total Number of Calibration Events	Percentile Rank for Station
6P40225	ES520001	100.0	208	208	100.0
6P40087	ES519999	100.0	75	75	99.8
6P38643	ES520127	100.0	130	130	99.5
6P16087	ES022771	100.0	282	282	99.3
6P32981	ES519973	98.3	114	116	99.1
6P39543	ES821938	97.6	81	83	98.8
6P44626	ES520270	92.2	71	77	98.6
6P37467	ES022557	88.1	111	126	98.4
6P10835	ES520211	85.5	53	62	98.1
6P35606	ES520270	81.4	131	161	97.9

6.3.2 Frequently Failing Span Gas Audits

Another time that the accuracy of analyzers is checked is during a span gas audit. Span gas audits were discussed in detail in Section 3.4.3. Here, the audit failure rate for each station was calculated. Stations with fewer than 2 audits in the dataset were excluded from the results (for HGB and DFW, stations with fewer than 6 audits were excluded from the results, leaving about half of the stations in the dataset. However, only 8 Austin stations received 6 or more audits, so the limit was reduced here). Most stations passed all of their audits. The ten stations with the highest span gas audit failure rates are shown below in Table 6-9. These are not as high as the highest rates for DFW/HGB stations, which were found to have between 85 and 100% failed audits.

Table 6-9. Percent of Span Gas Audits that were Failed

Station ID	Analyzer ID	Percent of Audits that were Failed	Number of Audits that were Failed	Total Number of Audits for Station	Percentile Rank for Station
6G35621	WW540124	75.0	3	4	100.0
6P42864	WW540132	66.7	2	3	99.8
6P39321	WW540134	57.1	4	7	99.5
6P32101	ES520421	57.1	4	7	99.3
6P44181	ES324160	50.0	1	2	99.0
6P42523	ES520670	50.0	1	2	98.8
6P41519	ES519979	50.0	2	4	98.5
6P40406	ES922341	50.0	1	2	98.3
6P40086	ES519969	50.0	2	4	98.0
6P39909	WW540233	50.0	1	2	97.8

6.3.3 Failure to Perform All Calibrations

Analyzers that are used for emissions inspections are required to undergo several types of calibration every 72-hours. If they do not receive all required calibrations, they are supposed to be locked out from performing I/M inspections until all calibrations are completed and passed. In Section 3.4.4, it was found that some analyzers pass only one calibration type without receiving all calibrations, and then proceed to perform inspections. Additionally, some analyzers receive one or more calibrations but do not pass them, and are allowed to continue performing inspections. Here, those results are examined to identify stations with a higher than average rate of performing incomplete or failed 72-hour calibrations, and then performing I/M inspections. The results for the top ten highest ranking stations are shown in Table 6-10, which gives the percentage of I/M inspections that were performed while the analyzer should have been locked out. Stations with fewer than 100 inspections in the dataset are excluded from the results. While most stations never perform any inspections while the analyzer should have been locked out, the table shows that some stations occasionally do. These rates are much lower than the maximum rates closer to 50% that were found for the DFW/HGB areas.

Table 6-10. Percent of Inspections When Analyzer Should Have Been Locked Out

Station ID	Analyzer ID	Percent of Inspections Performed on Analyzer that should have been locked out	Number of Inspections on Analyzer that should have been locked out	Total Number of Inspections for Station	Percentile Rank for Station
6P16397	ES520124	7.0	13	185	100.0
6P41794	ES022864	4.6	8	175	99.8
6P33577	ES520115	3.8	5	132	99.6
6P36647	ES520337	3.6	4	111	99.3
6P41090	ES022627	2.8	5	180	99.1
6P16512	ES520140	1.9	7	359	98.9
6P41789	ES122966	1.9	7	368	98.7
6P32800	ES520215	1.8	7	382	98.4
6P43124	ES223677	1.8	2	113	98.2
6P09379	ES223764	1.4	2	139	98.0

6.4 Data Entry Issues

Several VID fields are subject to manual data entry by inspectors during the inspection process. Consistently unusual data entry patterns can be detected at certain stations when the data are analyzed. This section presents the analysis results for several data entry metrics.

6.4.1 Consistently Entering Repair Type as "Misc"

Repairs performed are categorized by inspectors into five different types: fuel system, ignition/electrical system, emissions system, engine-mechanical, and miscellaneous repairs. Miscellaneous repairs accounted for approximately 40% of the repairs recorded in the TIMS during the most recent analysis period. At certain stations, miscellaneous repairs account for much more than that. The ten stations with the highest percentages of miscellaneous repairs are presented in Table 6-11. Stations that performed fewer than 100 inspections following repairs are excluded from the results. These results are similar to those that were found for the DFW/HGB areas.

Table 6-11. Miscellaneous Repair Percentage

Station ID	Percent of "Misc" repairs	Number of "Misc" repairs	Total Repairs	Percentile Rank for Station
6P44977	99.0	100	101	100.0
6P36445	99.0	678	685	99.6
6P42864	98.7	156	158	99.2
6P40319	98.0	481	491	98.8
6P40752	91.7	155	169	98.3
6P36038	89.0	299	336	97.9
6P33725	86.1	426	495	97.5
6P23054	85.6	113	132	97.1
6P40711	81.9	104	127	96.7
6P40030	79.7	106	133	96.3

6.4.2 Consistently Entering Repair Cost as $0

Repairs performed must also be recorded with an associated repair cost. Repairs recorded with a cost of $0 accounted for approximately one-half of the values in the TIMS during the most recent analysis period. At certain stations, zero-cost repairs account for much more than that. A summary of stations with a high percentage of zero-cost repairs is presented in Table 6-12. Stations that performed fewer than 100 inspections following repairs are excluded from the results. These results are similar to those that were found for the DFW/HGB areas.

Table 6-12. Zero-Cost Repair Percentage

Station ID	Percent of $0 Repairs	Number of $0 Repairs	Total Number of Repairs	Percentile Rank for Station
6P44977	100.0	100	100	100.0
6P40868	100.0	163	163	98.4
6P40711	100.0	114	114	96.8
6P36445	100.0	685	685	95.2
6P35269	100.0	496	496	93.7
6P35087	100.0	268	268	92.1

Station ID	Percent of $0 Repairs	Number of $0 Repairs	Total Number of Repairs	Percentile Rank for Station
6P32078	100.0	106	106	90.5
6P16688	100.0	137	137	88.9
6P33565	99.9	672	673	87.3
6P42279	99.8	846	848	85.7

6.4.3 VIN Check Digit Errors

In the 2009 IM Evaluation Report for DFW/HGB, about 1.5% of VINs on record contained a bad check digit or an illegal character. More recently, this year and in the 2012 report for those same programs, closer to 0.1% of VINs contained a bad check digit, representing such a small portion of total inspections that that metric was not used for the 2012 analysis. For the same reason, this metric was not used in the 2014 analysis. Most VINS are likely pre-populated through the record retrieval during the analyzer's initial "get-info" call, or are entered by bar-code reader.

6.4.4 Anomalous Inspection Sequences (other than 1P or FP)

Each vehicle that participates in the I/M program produces a brief history when it is inspected, repaired, and retested. 98.1% of the vehicles that participate in the program have a repair sequence of either pass (P) or fail-pass (FP). The remaining portion of the fleet consists of vehicles with histories that contain multiple passes or fails. Table 6-13 lists stations that were in contact at some point with vehicles that had anomalous inspection sequences. Stations that performed fewer than 100 inspections are excluded from the results. These results are similar, but slightly lower, than those found for the DFW/HGB areas.

Table 6-13. Anomalous Inspection Sequence Percentage

Station ID	Percent of Inspections with Odd Sequence	Number of Inspections with Odd Sequence	Total Inspections	Percentile Rank for Station
6P44658	9.8	64	654	100.0
6P44121	9.6	34	355	99.8
6P44959	9.5	20	210	99.5
6P41226	8.7	70	804	99.3
6P42864	8.1	44	544	99.1
6P41917	8.0	58	728	98.9
6P39846	7.8	132	1695	98.6
6P31821	7.5	225	2982	98.4
6P10865	7.5	234	3122	98.2
6P33872	7.4	30	405	98.0

6.5 Anomalous Test Results

In Section 3.4.2, several types of tailpipe inspection results displayed emissions concentrations that are not consistent with those expected for stoichiometric combustion. These include CO_2 levels higher than 16%, O_2 levels near ambient concentrations, and high dilution correction factors. In this section the rate of each of these anomalies by station is investigated.

6.5.1 Tailpipe Inspections with CO_2 Greater Than 16%

Table 6-14 presents stations with a high percentage of vehicles with TSI tests having CO_2 readings greater than 16%, outside the normal combustion range. Stations that performed fewer than 100 inspections are excluded from the table. It can be seen that only two stations had even a moderately high result on this metric. These results are much lower than the corresponding results for inspections in DFW/HGB.

Table 6-14. Percent of Inspections with CO_2 Greater Than 16%

Station ID	Percent of Inspections with CO_2 Greater Than 16%	Number of Inspections with CO_2 Greater Than 16%	Total Number of Inspections for Station	Percentile Rank for Station
6P42998	10.0	11	110	100.0
6P40840	9.3	31	332	99.5
6P34907	4.4	10	228	99.1
6P38187	3.1	5	160	98.6
6P39412	2.8	9	321	98.2
6P39036	2.7	3	112	97.7
6P40398	2.2	8	363	97.3
6P37114	1.7	9	530	96.8
6P42224	1.1	3	267	96.4
6P16129	0.9	8	850	95.9

6.5.2 Tailpipe Inspections with O_2 Greater than 20.5%

Table 6-15 presents stations with a high percentage of vehicles with TSI tests having O_2 readings greater than 20.5%, which is outside the normal combustion range and is very close to the ambient O_2 concentration of 20.9%. Stations that performed fewer than 100 inspections are excluded from the table. These results are much lower than the corresponding results for inspections in DFW/HGB.

Table 6-15. Percent of Inspections with O_2 Greater Than 16%

Station ID	Percent of Inspections with O2 Greater Than 20.5%	Number of Inspections with O2 Greater Than 20.5%	Total Number of Inspections for Station	Percentile Rank for Station
6P37623	61.2	90	147	100.0
6P36138	60.3	70	116	99.5
6P36659	29.8	195	655	99.1
6P16372	24.2	154	637	98.6
6P36664	22.4	38	170	98.2
6P40717	21.3	356	1669	97.7
6P40225	12.0	24	200	97.3
6P35366	8.8	9	102	96.8
6P32880	4.5	6	134	96.4
6P35606	3.6	12	331	95.9

6.6 Tailpipe Inspections with High Dilution Correction Factor Differences

Table 6-16 presents stations with a high rate of inspections where the CO/CO_2-based DCF was out of agreement with the O_2-based DCF. This indicates a problem with the measurement of one or more of the pollutants. Stations that performed fewer than 100 inspections are excluded from the table. It can be seen from the table that the top ten stations had differences between the two DCFs for every inspection. It should be noted that there is overlap between the results in this section and the results in the previous two sections (CO_2 greater than 16% and O_2 greater than 20.5%), since the DCF is based on CO, CO_2, and O_2 measurements. Anomalous concentrations are also indicators of problems with the emissions measurements, and are also likely to result in a disagreement between the two DCFs. These results are much lower than the corresponding results for inspections in DFW/HGB.

Table 6-16. Percent of Inspections with Disagreement Between CO/CO_2 and O_2 DCFs

Station ID	Percent of Inspections with DCF Disagreement	Number of Inspections with DCF Disagreement	Total Number of Inspections for Station	Percentile Rank for Station
6P16372	75.4	480	637	100.0
6P37623	74.1	109	147	99.5
6P36138	62.1	72	116	99.1
6P40717	54.4	908	1669	98.6
6P32800	49.7	83	167	98.2
6P36659	46.6	305	655	97.7
6P43139	39.7	58	146	97.3
6P36664	34.1	58	170	96.8
6P40520	27.1	56	207	96.4
6P35366	24.5	25	102	95.9

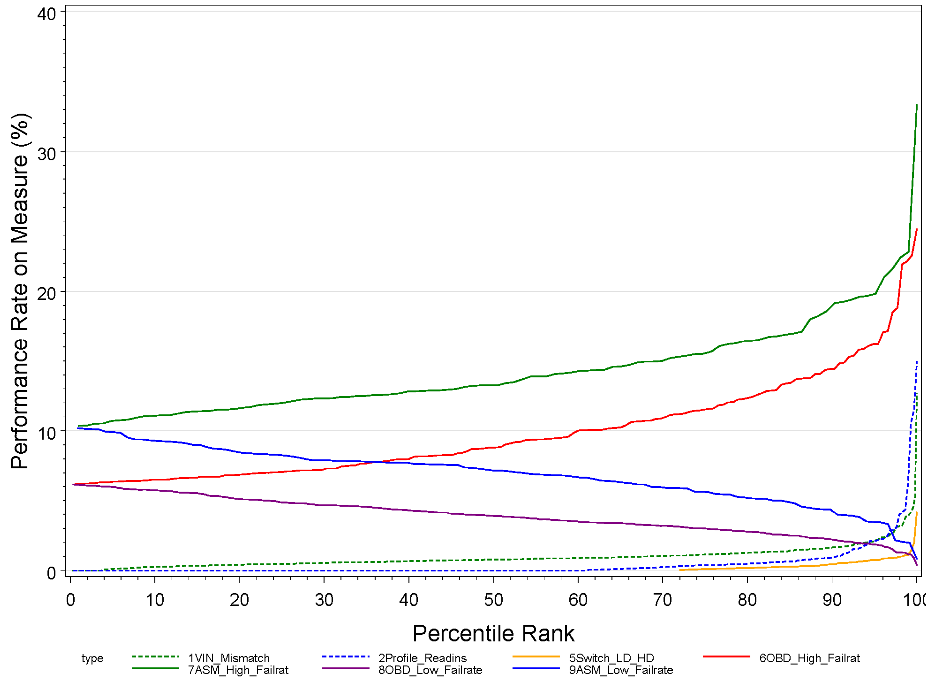
6.7 Compilation of Percentile Rankings

After a separate ranking was assigned for each of the measures of errors of commission, the ranks were used to score the stations and identify the stations with the highest likelihood of either errors of commission, or errors of omission.

Some of the details of the ranking procedure and the resulting ranks make it challenging to combine the ranks for an overall score. First, most stations did not perform enough inspections of one type or another (i.e., OBD retests, TSI inspections, etc.) to receive a rank for all of the measures. Secondly, it is known from the measures listed in the previous sections that the range of results was not the same for each measure. For example, for the OBD VIN mismatch section, about 90% of stations had very low VIN mismatch rates. The remaining 10% had VIN mismatch rates that might be cause for concern, or about the top 10 percentiles in the ranking. In contrast, for the tailpipe inspection being switched from light-duty to heavy-duty in order to pass, at least 95% of stations had reasonably low rates of switching, and only the top 5% of stations would lead one to suspect possible fraud. Figure 6-3 below shows the distribution of the results and the rankings that were created from those results for each of the measures of errors of commission (from sub-sections 6.1 and 6.2).

The green dashed line for the OBD VIN mismatch shows that the stations from 0 to the 90th percentile had a very low percentage of mismatches. Above the 90th percentile, the mismatch rate quickly increases. Similarly, the blue dashed line for OBD electronic readiness profile show that stations up to the 90th percentile had a low rate of mismatches. For one of the tailpipe measures, the rate of retests switched from light-duty to HD, the stations below about the 95th percentile had very low results. Above the 95th percentile, the rate of potentially fraudulent results rapidly increases. The red and purple lines show the rankings for OBD inspection failure rates. For both of those lines, the 0th percentile is the mean failure rate over all stations. The percentiles for the red line increase as the failure rate increases further above the mean, while the percentiles for the purple line increase as the failure rate decreases further below the mean. For both of these, one sees a "break" at about the 90th percentile, where the OBD fail rate starts to change rapidly as the percentile continues to increase. The solid green and blue lines show similar results for the ASM failure rates, and again the "break" for the low ASM failure rates is close to the 90th percentile.

Figure 6-3. Distribution of Results and Percentiles for Errors of Commission



At percentiles below the "break" (the percentile above which the results rapidly worsen) in each line on Figure 6-3, it is probably not likely that the station is performing that type of fraudulent activity that can be detected through this analysis. At percentiles above the break, there is evidence for suspicion of fraud. Thus, the visual results of the location of the break were used to create an indicator flag for each of the measures. Stations above the break for the given measure were flagged. Then, the total number of flags that each station received was determined. The list of all stations was then sorted by the descending number of flags received, in order to create a final list in order of most-suspicious to least-suspicious. The results for the top 50 most suspicious stations are given in Table 6-17. Table 6-18 gives the results for an additional 50 stations from near the middle of the range of results for comparison purposes.

Some of the first lines in Table 6-17 show stations that should be investigated (if they haven't already been, as a result of triggers or other audits). For example, the first lines show stations that have high rates of VIN mismatches and electronic profile mismatches (both for OBD inspections). This might indicate clean-piping, except that most of these stations also have high ranks for high failure rates for the OBD inspection. Similar combinations can be seen for the TSI clean-piping measures and TSI failure rates. If this table were to be used for identifying stations for enforcement, audits, etc., the user would have to look through the lines and identify the stations with the clearest combination of factors for the type of fraud being considered. The entire table with all stations is available in electronic format.

A similar strategy was used for identifying the stations most likely to need some improvement on proper inspection procedures. The results of errors of omission from the measures in the previous sub-sections were used here. Figure 6-4 shows the distribution of the results vs. the percentiles for each of the measures. Some of the "break" points are difficult to discern, such as that for the green line, which is for calibrations that began with the analyzer out of tolerance. After consideration of Figure 6-4, the "break" percentiles were assigned at the 80th percentile for analyzers out of tolerance, the 80th percentile for span gas audit failures, the 95th percentile for performing inspections when analyzer is not fully calibrated and should be locked out, the 95th percentile for inspections with unusual pass/fail sequences, the 60th percentile for stations entering repair types as "Misc", the 30th percentile for stations entering repair costs as $0, the 95th percentile for inspections with CO_2 greater than 16%, the 95th percentile for inspections with O_2 greater than 20.5%, and the 85th percentile for inspections with disagreement between the DCFs. It should be noted these percentile flags were determined subjectively and could be adjusted over time as one becomes more familiar with how sensitive each metric is for detecting irregular calibration or test activities.

The results for the top 50 worst-performing stations for errors of omission are listed in Table 6-19. Some of the rows do appear to show a clear picture of the inspectors at some stations having particular trouble entering data accurately and completely, with high scores for repair types entered as "Misc", and repair costs entered as $0. Other stations may have consistent problems with their analyzers, with the analyzer often out of tolerance at the beginning of a calibration, and a high rate of inspections with CO_2 greater than 16% and O_2 greater than 20.5%. Again, the table could be used to identify different types of enforcement that are indicated by the combinations of results on each line.

Table 6-17. Top 50 Most Suspicious Stations for Errors of Commission

Station ID	Sum of Rank Flags	Max Rank for Station	Individual Ranks								
			OBD VIN Mismatch	OBD Profile/ Readiness	Tailpipe Close-In-Time	Switch ASM to TSI	Switch LD to HD	OBD High Fail Rate	TSI High Fail Rate	OBD Low Fail Rate	TSI Low Fail Rate
6P41917	3	100	98	77	Not used for Austin.		63	98	100	.	.
6P38785	3	100	100	95	.	.	47	97	68	.	.
6P39239	3	100	100	99	.	.	48	94	70	.	.
6P41436	3	99	88	92	.	.	99	93	74	.	.
6P39846	3	98	98	97	.	.	84	98	71	.	.
6P39448	3	97	94	97	.	.	81	84	97	.	.
6P28318	2	100	30	9	.	.	100	.	.	67	92
6P35331	2	100	32	22	.	.	.	.	.	100	100
6P42864	2	100	93	57	.	.	94	100	87	.	.
6P39560	2	100	97	100	.	.	.	.	.	14	.
6P37116	2	99	95	73	.	.	86	55	99	.	.
6P42293	2	99	99	.	.	.	.	99	.	.	.
6P40868	2	98	94	98	.	.	60	49	63	.	.
6P16528	2	98	98	98	.	.	9	89	66	.	.
6P41953	2	98	93	53	.	.	98	.	.	50	24
6P38126	2	98	97	98	.	.	42	7	.	.	.
6P16646	2	98	14	5	.	.	98	.	.	97	.
6P23086	2	98	96	.	.	.	.	.	.	98	81
6P44959	2	97	96	87	.	.	72	97	.	.	.
6P07257	2	97	30	2	.	.	5	.	.	95	97
6P30840	2	96	71	96	.	.	16	.	.	92	.
6P40030	2	96	96	45	.	.	92	66	95	.	.
6P40876	2	96	93	76	.	.	96	75	89	.	.
6P39918	2	95	83	80	.	.	88	95	92	.	.
6P35044	2	95	92	.	.	.	.	.	.	56	95
6P25665	2	94	4	94	.	.	.	.	.	92	.
6P36799	2	94	79	29	.	.	35	92	94	.	.
6P40717	2	92	92	82	.	.	84	90	64	.	.
6P40929	2	91	90	91	.	.	60	87	43	.	.
6P32530	1	100	89	100	.	.	20	58	34	.	.
6P40485	1	100	100	.	.	.	.	.	54	48	.
6P35109	1	100	84	21	.	.	100	27	.	.	17

Station ID	Sum of Rank Flags	Max Rank for Station	Individual Ranks								
			OBD VIN Mismatch	OBD Profile/ Readiness	Tailpipe Close-In-Time	Switch ASM to TSI	Switch LD to HD	OBD High Fail Rate	TSI High Fail Rate	OBD Low Fail Rate	TSI Low Fail Rate
6F16722	1	100	0	.	.	.	.	.	.	100	.
6P16374	1	99	89	.	.	.	.	99	.	.	.
6P39028	1	99	99	.	.	.	.	47	.	.	.
6P16087	1	99	70	99	.	.	95	.	.	80	66
6P04783	1	99	20	.	.	.	.	.	.	99	.
6P41022	1	99	37	.	.	.	.	.	.	65	99
6F31011	1	99	99	.	.	.	.	.	.	.	.
6P38133	1	99	19	36	.	.	99	.	31	30	.
6P44439	1	99	16	.	.	.	.	.	.	99	.
6P39876	1	99	99	.	.	.	.	62	.	.	.
6P39036	1	99	77	41	.	.	99	71	55	.	.
6P41789	1	99	90	99	.	.	62	.	.	70	49
6P00484	1	99	67	.	.	.	.	.	.	99	.
6P44900	1	98	98	.	.	.	.	9	.	.	.
6P02869	1	98	75	1	.	.	3	.	.	61	98
6P36973	1	98	31	90	.	.	98	.	52	29	.
6P41519	1	98	15	.	.	.	.	.	.	98	.
6P40859	1	98	48	51	.	.	59	.	98	65	.

Table 6-18. 50 Mid-Range Stations for Errors of Commission

Station ID	Sum of Rank Flags	Max Rank for Station	Individual Ranks								
			OBD VIN Mismatch	OBD Profile/ Readiness	Tailpipe Close-In-Time	Switch ASM to TSI	Switch LD to HD	OBD High Fail Rate	TSI High Fail Rate	OBD Low Fail Rate	TSI Low Fail Rate
6P42279	0	85	65	69	Not used for Austin		74	85	61	.	.
6P32101	0	85	44	12	.	.	19	.	.	85	.
6P16507	0	85	54	5	.	.	85	30	.	.	71
6P35828	0	85	85	79	.	.	31	.	.	27	.
6P42138	0	85	51	.	.	.	.	.	.	85	.
6P40587	0	85	39	50	.	.	85	.	.	44	48
6P32366	0	85	78	85	.	.	20	.	24	14	.
6P43193	0	85	.	.	.	.	.	85	.	.	.
6P40379	0	84	12	47	.	.	54	77	84	.	.
6P39866	0	84	72	44	.	.	51	.	.	84	.
6P40933	0	84	84	.	.	.	.	34	.	.	.
6P38635	0	84	53	37	.	.	44	.	.	84	.
6P39944	0	84	61	84	.	.	52	.	.	59	.
6P35881	0	84	19	24	.	.	32	.	.	13	84
6P40398	0	84	84	48	.	.	55	1	56	.	.
6P32084	0	84	84	.	.	.	19	.	.	5	.
6P34907	0	84	26	21	.	.	28	.	.	84	59
6P38797	0	84	74	40	.	.	84	82	17	.	.
6P43089	0	84	15	84	.	.	68	68	.	.	.
6P45114	0	83	83	.	.	.	.	7	.	.	.
6P45219	0	83	4	.	.	.	.	83	.	.	.
6P35606	0	83	55	23	.	.	83	25	9	.	.
6P27656	0	83	21	.	.	.	.	.	.	83	.
6P36038	0	83	83	25	.	.	80	71	26	.	.
6P37286	0	83	20	32	.	.	38	.	.	72	83
6P36867	0	83	39	30	.	.	83	.	.	25	51
6P35165	0	83	17	22	.	.	29	.	.	83	.
6P37845	0	83	23	35	.	.	83	.	.	46	8
6P33258	0	83	62	83	.	.	25	.	.	54	.
6P35269	0	82	71	22	.	.	30	82	13	.	.
6P33565	0	82	41	63	.	.	82	.	.	32	61
6P41006	0	82	16	.	.	.	.	.	.	82	.

Station ID	Sum of Rank Flags	Max Rank for Station	Individual Ranks								
			OBD VIN Mismatch	OBD Profile/ Readiness	Tailpipe Close-In-Time	Switch ASM to TSI	Switch LD to HD	OBD High Fail Rate	TSI High Fail Rate	OBD Low Fail Rate	TSI Low Fail Rate
6P28280	0	82	12	9	.	.	14	.	.	38	82
6P44181	0	82	82	.	.	.	.	.	.	47	.
6P23028	0	82	82	.	.	.	.	53	.	.	.
6P42951	0	82	56	82	.	.	67	67	.	.	.
6P41955	0	82	82	53	.	.	63	55	.	.	.
6P37134	0	82	38	63	.	.	82	.	20	2	.
6P38644	0	82	34	39	.	.	45	.	82	52	.
6P44516	0	82	38	.	.	.	.	.	.	82	.
6P41629	0	81	81	.	.	.	.	.	.	9	.
6P32880	0	81	81	15	.	.	24	19	.	.	6
6P38634	0	81	68	.	.	.	.	.	.	81	.
6P33728	0	81	43	81	.	.	26	.	.	40	80
6G31114	0	81	81	.	.	.	.	.	.	79	.
6P38640	0	81	7	38	.	.	45	.	.	81	1
6P32877	0	81	81	.	.	.	.	.	.	0	.
6P39458	0	81	75	42	.	.	75	81	15	.	.
6P39428	0	81	53	42	.	.	81	.	.	3	19
6P36582	0	80	59	26	.	.	80	5	57	.	.

Figure 6-4. Distribution of Results and Percentiles for Errors of Omission

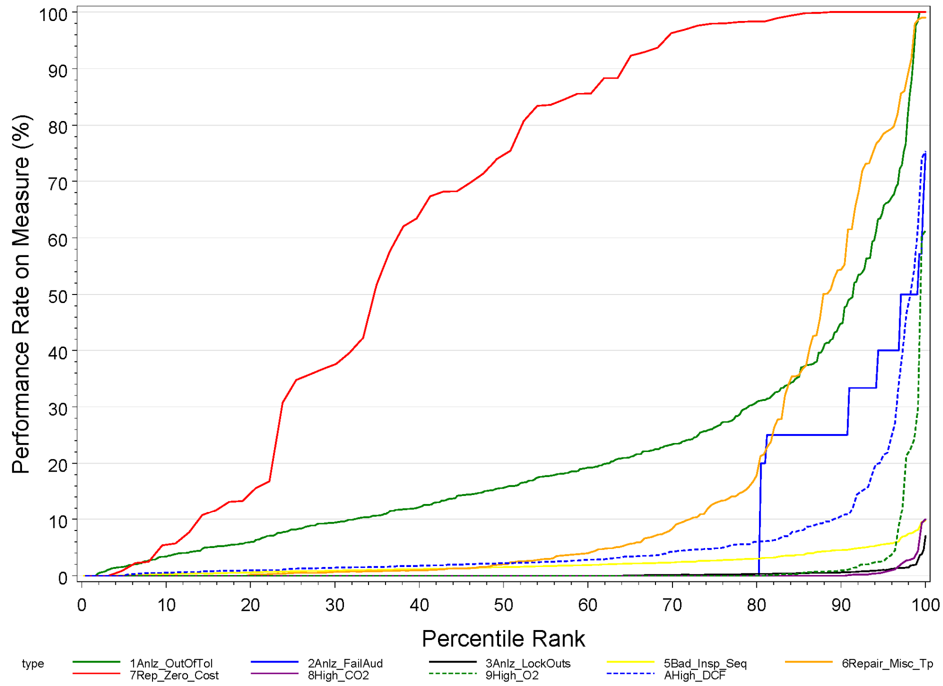


Table 6-19. Top 50 Stations with Errors of Omission

Station ID	Sum of Rank Flags	Max Rank for St.	Individual Ranks								
			Anlz Out of Tol	Anlz Fail Audits	Anlz Lock Out	Bad P/F Seq	Repair Type "Misc"	Repair Cost $0	CO_2 gt 16%	O_2 gt 20.5%	DCF Disagreement
6P16372	4	100	92	12	79	98	78	6	10	99	100
6P40225	4	100	100	93	44	75	.	.	69	97	95
6P42998	4	100	97	94	58	90	.	.	100	80	89
6P40717	4	99	85	66	77	97	77	11	76	98	99
6P40406	4	98	97	98	45	50	45	.	95	65	87
6P37134	4	97	79	44	66	57	95	41	92	44	38
6P37134	4	97	97	86	90	57	95	41	92	44	38
6P16129	4	96	90	10	89	18	90	33	96	9	56
6P37236	4	94	93	45	30	40	84	83	51	45	74
6P37236	4	94	94	45	82	40	84	83	51	45	74
6P40484	4	93	88	63	70	21	16	.	72	66	88
6P40484	4	93	89	93	89	21	16	.	72	66	88
6P38785	4	93	93	87	38	98	73	24	61	55	93
6P39428	4	88	19	57	68	56	65	49	64	83	83
6P39428	4	88	80	88	83	56	65	49	64	83	83
6P37623	3	100	70	48	33	64	65	.	54	100	100
6P40840	3	100	63	67	48	51	23	.	100	69	86
6P40840	3	100	98	67	85	51	23	.	100	69	86
6P41090	3	99	96	90	99	43	.	.	.	.	.
6P41789	3	99	36	71	98	34	58	.	84	75	23
6P41789	3	99	63	97	99	34	58	.	84	75	23
6P32800	3	98	91	25	98	52	27	.	27	24	98
6P36038	3	98	86	37	27	83	98	19	41	91	88
6P35606	3	98	98	35	69	57	8	.	38	96	90
6P40398	3	97	52	97	69	55	80	17	97	64	71
6P43139	3	97	94	94	59	96	20	.	90	81	97
6P43139	3	97	94	94	59	96	20	.	90	81	97
6P37113	3	96	83	86	96	46	.	.	.	.	.
6P40030	3	96	49	92	43	88	96	70	68	62	40
6P37592	3	96	90	48	96	67	10	.	54	48	95
6P32900	3	95	24	27	83	37	93	59	29	24	74
6P32900	3	95	77	95	90	37	93	59	29	24	74
6P38639	3	95	90	53	95	52	12	.	59	95	94

Station ID	Sum of Rank Flags	Max Rank for St.	Individual Ranks								
			Anlz Out of Tol	Anlz Fail Audits	Anlz Lock Out	Bad P/F Seq	Repair Type "Misc"	Repair Cost $0	CO_2 gt 16%	O_2 gt 20.5%	DCF Disagreement
6P36960	3	95	7	85	30	90	95	62	48	41	24
6P41004	3	95	95	68	75	48	82	79	80	71	32
6P16715	3	94	22	15	11	97	88	84	15	86	72
6P16715	3	94	62	94	11	97	88	84	15	86	72
6P16715	3	94	62	94	67	97	88	84	15	86	72
6P36338	3	94	85	38	69	27	94	56	43	37	19
6P16083	3	94	83	80	7	5	45	.	.	.	.
6P16083	3	94	83	82	94	5	45	.	.	.	.
6P37611	3	93	81	48	33	86	63	37	93	48	81
6P41296	3	93	44	90	51	44	79	.	81	93	86
6P39846	3	92	92	88	42	99	69	.	67	60	48
6P35888	3	89	89	36	71	88	70	67	40	36	68
6P40460	3	89	82	89	45	81	15	.	72	85	85
6P32481	3	87	87	84	19	21	79	.	.	.	.
6P16397	2	100	81	12	100	12	2	.	.	.	.
6P44977	2	100	.	.	64	85	100	100	.	.	.
6P16372	4	100	92	12	79	98	78	6	10	99	100

7.0 References

1. "Draft Guidance on Use of In-Program Data for Evaluation of I/M Program Performance," EPA420-P-01-003, www.epa.gov/otaq/regs/im/obd/p01003.pdf, August 2001.

2. "Guidance on Use of Remote Sensing for Evaluation of I/M Program Performance," EPA420-B-04-010, www.epa.gov/otaq/regs/im/obd/420b04010.pdf, July 2004.

3. Evaluation of the Texas Inspection and Maintenance Programs in the Dallas/Fort Worth and Houston-Galveston-Brazoria Nonattainment Areas", Final Report, Eastern Research Group November 7, 2013.

4. Evaluation of the Texas Inspection and Maintenance Programs in the Dallas/Fort Worth and Houston-Galveston-Brazoria Nonattainment Areas", Final Report, Eastern Research Group November 30, 2006.

5. Evaluation of the Texas Inspection and Maintenance Programs in the Dallas/Fort Worth and Houston-Galveston-Brazoria Nonattainment Areas", Final Report, Eastern Research Group November 30, 2009.

6. Evaluation of the Texas Inspection and Maintenance Programs in the Dallas/Fort Worth and Houston-Galveston-Brazoria Nonattainment Areas", Final Report, Eastern Research Group July 31, 2012.

7. T.H. DeFries, A.D. Burnette, S. Kishan, Y. Meng, "Evaluation of the Texas Motorist's Choice Program," ERG Report No. TNRCC-000531, May 31, 2000.

Appendix A

DTC Groups

Table A-1. Evap DTCs

DTC	DTC Description	DTC	DTC Description
P0093	Fuel System Leak Detected - Large Leak	P0496	Evap High Purge Flow
P0094	Fuel System Leak Detected - Small Leak	P0497	Evap Low Purge Flow
P0440	Evap Malfunction	P0498	Evap Vent Valve Control Circuit Low
P0441	Evap Incorrect Purge Flow	P0499	Evap Vent Valve Control Circuit High
P0442	Evap Leak Detected (small leak)	P2024	Evap Fuel Vapor Temperature Sensor Circuit
P0443	Evap Purge Control Valve Circuit	P2025	Evap Fuel Vapor Temperature Sensor Performance
P0444	Evap Purge Control Valve Circuit Open	P2026	Evap Fuel Vapor Temperature Sensor Circuit Low Voltage
P0445	Evap Purge Control Valve Circuit Shorted	P2027	Evap Fuel Vapor Temperature Sensor Circuit High Voltage
P0446	Evap Vent Control Circuit Malfunction	P2028	Evap Fuel Vapor Temperature Sensor Circuit Intermittent
P0447	Evap Vent Control Circuit Open	P2400	Evap Leak Detection Pump Control Circuit/Open
P0448	Evap Vent Control Circuit Shorted	P2401	Evap Leak Detection Pump Control Circuit Low
P0449	Evap Vent Valve/Solenoid Circuit Malfunction	P2402	Evap Leak Detection Pump Control Circuit High
P0450	Evap Pressure Sensor Malfunction	P2403	Evap Leak Detection Pump Sense Circuit/Open
P0451	Evap Pressure Sensor Range/Performance	P2404	Evap Leak Detection Pump Sense Circuit Range/Performance
P0452	Evap Pressure Sensor Low Input	P2405	Evap Leak Detection Pump Sense Circuit Low
P0453	Evap Pressure Sensor High Input	P2406	Evap Leak Detection Pump Sense Circuit High
P0454	Evap Pressure Sensor Intermittent	P2407	Evap Leak Detection Pump Sense Circuit Intermittent/Erratic
P0455	Evap Leak Detected (gross leak)	P2408	Fuel Cap Sensor/Switch Circuit
P0456	Evap Leak Detected (very small leak)	P2409	Fuel Cap Sensor/Switch Circuit Range/Performance
P0457	Evap Leak Detected (fuel cap loose/off)	P2410	Fuel Cap Sensor/Switch Circuit Low
P0458	Evap Purge Control Valve Circuit Low	P2411	Fuel Cap Sensor/Switch Circuit High
P0459	Evap Purge Control Valve Circuit High	P2412	Fuel Cap Sensor/Switch Circuit Intermittent/Erratic
P0465	Purge Flow Sensor Circuit Malfunction	P2418	Evap Switching Valve Control Circuit / Open
P0466	Purge Flow Sensor Circuit Range/Performance	P2419	Evap Switching Valve Control Circuit Low
P0467	Purge Flow Sensor Circuit Low Input	P2420	Evap Switching Valve Control Circuit High
P0468	Purge Flow Sensor Circuit High Input	P2421	Evap Vent Valve Stuck Open
P0469	Purge Flow Sensor Circuit Intermittent	P2422	Evap Vent Valve Stuck Closed

Table A-2. Catalyst DTCs[5]

DTC	DTC Description	DTC	DTC Description
P0420	Catalyst System Efficiency Below Threshold	P0431	Warm Up Catalyst Efficiency Below Threshold
P0421	Warm Up Catalyst Efficiency Below Threshold	P0432	Main Catalyst Efficiency Below Threshold
P0422	Main Catalyst Efficiency Below Threshold	P0433	Heated Catalyst Efficiency Below Threshold
P0423	Heated Catalyst Efficiency Below Threshold	P0434	Heated Catalyst Temperature Below Threshold
P0424	Heated Catalyst Temperature Below Threshold	P0435	Catalyst Temperature Sensor
P0425	Catalyst Temperature Sensor	P0436	Catalyst Temperature Sensor Range/Performance
P0426	Catalyst Temperature Sensor Range/Performance	P0437	Catalyst Temperature Sensor Low
P0427	Catalyst Temperature Sensor Low	P0438	Catalyst Temperature Sensor High
P0428	Catalyst Temperature Sensor High	P0439	Catalyst Heater Control Circuit
P0429	Catalyst Heater Control Circuit	P2423	HC Adsorption Catalyst Efficiency Below Threshold
P0430	Catalyst System Efficiency Below Threshold	P2424	HC Adsorption Catalyst Efficiency Below Threshold

Table A-3. EGR DTCs

DTC	DTC Description	DTC	DTC Description
P0400	EGR Flow	P0489	EGR Control Circuit Low
P0401	EGR Flow Insufficient Detected	P0490	EGR Control Circuit High
P0402	EGR Flow Excessive Detected	P2141	EGR Throttle Control Circuit Low
P0403	EGR Control Circuit	P2142	EGR Throttle Control Circuit High
P0404	EGR Control Circuit Range/Performance	P2143	EGR Vent Control Circuit/Open
P0405	EGR Sensor "A" Circuit Low	P2144	EGR Vent Control Circuit Low
P0406	EGR Sensor "A" Circuit High	P2145	EGR Vent Control Circuit High
P0407	EGR Sensor "B" Circuit Low	P2413	EGR System Performance
P0408	EGR Sensor "B" Circuit High	P2425	EGR Cooling Valve Control Circuit/Open
P0409	EGR Sensor "A" Circuit	P2426	EGR Cooling Valve Control Circuit Low
P0486	EGR Sensor "B" Circuit	P2427	EGR Cooling Valve Control Circuit High
P0487	EGR Throttle Position Control Circuit	P2428	Exhaust Gas Temperature Too High
P0488	EGR Throttle Position Control Range/Perf	P2429	Exhaust Gas Temperature Too High

[5] Includes heated catalyst DTCs, although none were present in the data analyzed for this study

Table A-4. O_2 System DTCs[6]

DTC	DTC Description	DTC	DTC Description
P0030	HO2S Heater Control Circuit	P0166	O2 Sensor Circuit No Activity Detected
P0031	HO2S Heater Control Circuit Low	P0167	O2 Sensor Heater Circuit
P0032	HO2S Heater Control Circuit High	P2195	O2 Sensor Signal Stuck Lean
P0036	HO2S Heater Control Circuit	P2196	O2 Sensor Signal Stuck Rich
P0037	HO2S Heater Control Circuit Low	P2197	O2 Sensor Signal Stuck Lean
P0038	HO2S Heater Control Circuit High	P2198	O2 Sensor Signal Stuck Rich
P0040	O2 Sensor Signals Swapped B1 S1/ B2 S1	P2231	O2 Sensor Signal Circuit Shorted to Heater Circuit
P0041	O2 Sensor Signals Swapped B1 S2/ B2 S2	P2232	O2 Sensor Signal Circuit Shorted to Heater Circuit
P0042	HO2S Heater Control Circuit	P2233	O2 Sensor Signal Circuit Shorted to Heater Circuit
P0043	HO2S Heater Control Circuit Low	P2234	O2 Sensor Signal Circuit Shorted to Heater Circuit
P0044	HO2S Heater Control Circuit High	P2235	O2 Sensor Signal Circuit Shorted to Heater Circuit
P0050	HO2S Heater Control Circuit	P2236	O2 Sensor Signal Circuit Shorted to Heater Circuit
P0051	HO2S Heater Control Circuit Low	P2237	O2 Sensor Positive Current Control Circuit/Open
P0052	HO2S Heater Control Circuit High	P2238	O2 Sensor Positive Current Control Circuit Low
P0053	HO2S Heater Resistance	P2239	O2 Sensor Positive Current Control Circuit High
P0054	HO2S Heater Resistance	P2240	O2 Sensor Positive Current Control Circuit/Open
P0055	HO2S Heater Resistance	P2241	O2 Sensor Positive Current Control Circuit Low
P0056	HO2S Heater Control Circuit	P2242	O2 Sensor Positive Current Control Circuit High
P0057	HO2S Heater Control Circuit Low	P2243	O2 Sensor Reference Voltage Circuit/Open
P0058	HO2S Heater Control Circuit High	P2244	O2 Sensor Reference Voltage Performance
P0059	HO2S Heater Resistance	P2245	O2 Sensor Reference Voltage Circuit Low
P0060	HO2S Heater Resistance	P2246	O2 Sensor Reference Voltage Circuit High
P0061	HO2S Heater Resistance	P2247	O2 Sensor Reference Voltage Circuit/Open
P0062	HO2S Heater Control Circuit	P2248	O2 Sensor Reference Voltage Performance
P0063	HO2S Heater Control Circuit Low	P2249	O2 Sensor Reference Voltage Circuit Low
P0064	HO2S Heater Control Circuit High	P2250	O2 Sensor Reference Voltage Circuit High
P0130	O2 Sensor Circuit	P2251	O2 Sensor Negative Current Control Circuit/Open
P0131	O2 Sensor Circuit Low Voltage	P2252	O2 Sensor Negative Current Control Circuit Low`

[6] Includes oxygen sensor and oxygen sensor heater

DTC	DTC Description	DTC	DTC Description
P0132	O2 Sensor Circuit High Voltage	P2253	O2 Sensor Negative Current Control Circuit High
P0133	O2 Sensor Circuit Slow Response	P2254	O2 Sensor Negative Current Control Circuit/Open
P0134	O2 Sensor Circuit No Activity Detected	P2255	O2 Sensor Negative Current Control Circuit Low
P0135	O2 Sensor Heater Circuit	P2256	O2 Sensor Negative Current Control Circuit High
P0136	O2 Sensor Circuit	P2270	O2 Sensor Signal Stuck Lean
P0137	O2 Sensor Circuit Low Voltage	P2271	O2 Sensor Signal Stuck Rich
P0138	O2 Sensor Circuit High Voltage	P2272	O2 Sensor Signal Stuck Lean
P0139	O2 Sensor Circuit Slow Response	P2273	O2 Sensor Signal Stuck Rich
P0140	O2 Sensor Circuit No Activity Detected	P2274	O2 Sensor Signal Stuck Lean
P0141	O2 Sensor Heater Circuit	P2275	O2 Sensor Signal Stuck Rich
P0142	O2 Sensor Circuit	P2276	O2 Sensor Signal Stuck Lean
P0143	O2 Sensor Circuit Low Voltage	P2277	O2 Sensor Signal Stuck Rich
P0144	O2 Sensor Circuit High Voltage	P2278	O2 Sensor Signals Swapped B1 S3 / B2 S3
P0145	O2 Sensor Circuit Slow Response	P2297	O2 Sensor Out of Range During Deceleration
P0146	O2 Sensor Circuit No Activity Detected	P2298	O2 Sensor Out of Range During Deceleration
P0147	O2 Sensor Heater Circuit	P2414	O2 Sensor Exhaust Sample Error
P0150	O2 Sensor Circuit	P2415	O2 Sensor Exhaust Sample Error
P0151	O2 Sensor Circuit Low Voltage	P2416	O2 Sensor Signals Swapped B1 S2 / B1 S3
P0152	O2 Sensor Circuit High Voltage	P2417	O2 Sensor Signals Swapped B2 S2 / B2 S3
P0153	O2 Sensor Circuit Slow Response	P2626	O2 Sensor Pumping Current Trim Circuit/Open
P0154	O2 Sensor Circuit No Activity Detected	P2627	O2 Sensor Pumping Current Trim Circuit Low
P0155	O2 Sensor Heater Circuit	P2628	O2 Sensor Pumping Current Trim Circuit High
P0156	O2 Sensor Circuit	P2629	O2 Sensor Pumping Current Trim Circuit/Open
P0157	O2 Sensor Circuit Low Voltage	P2630	O2 Sensor Pumping Current Trim Circuit Low
P0158	O2 Sensor Circuit High Voltage	P2631	O2 Sensor Pumping Current Trim Circuit High
P0159	O2 Sensor Circuit Slow Response	P2A00	O2 Sensor Circuit Range/Performance
P0160	O2 Sensor Circuit No Activity Detected	P2A01	O2 Sensor Circuit Range/Performance
P0161	O2 Sensor Heater Circuit	P2A02	O2 Sensor Circuit Range/Performance
P0162	O2 Sensor Circuit	P2A03	O2 Sensor Circuit Range/Performance
P0163	O2 Sensor Circuit Low Voltage	P2A04	O2 Sensor Circuit Range/Performance
P0164	O2 Sensor Circuit High Voltage	P2A05	O2 Sensor Circuit Range/Performance
P0165	O2 Sensor Circuit Slow Response		

Table A-6. Secondary Air Intake System DTCs

DTC	DTC Description	DTC	DTC Description
P0410	Secondary Air Injection System	P2431	Secondary Air Injection System Air Flow/Pressure Sensor Circuit Range/Performance
P0411	Secondary Air Injection System Incorrect Flow Detected	P2432	Secondary Air Injection System Air Flow/Pressure Sensor Circuit Low
P0412	Secondary Air Injection System Switching Valve "A" Circuit	P2433	Secondary Air Injection System Air Flow/Pressure Sensor Circuit High
P0413	Secondary Air Injection System Switching Valve "A" Circuit Open	P2434	Secondary Air Injection System Air Flow/Pressure Sensor Circuit Intermittent/Erratic
P0414	Secondary Air Injection System Switching Valve "A" Circuit Shorted	P2435	Secondary Air Injection System Air Flow/Pressure Sensor Circuit
P0415	Secondary Air Injection System Switching Valve "B" Circuit	P2436	Secondary Air Injection System Air Flow/Pressure Sensor Circuit Range/Performance
P0416	Secondary Air Injection System Switching Valve "B" Circuit Open	P2437	Secondary Air Injection System Air Flow/Pressure Sensor Circuit Low
P0417	Secondary Air Injection System Switching Valve "B" Circuit Shorted	P2438	Secondary Air Injection System Air Flow/Pressure Sensor Circuit High
P0418	Secondary Air Injection System Control "A" Circuit	P2439	Secondary Air Injection System Air Flow/Pressure Sensor Circuit Intermittent/Erratic
P0419	Secondary Air Injection System Control "B" Circuit	P2440	Secondary Air Injection System Switching Valve Stuck Open
P0491	Secondary Air Injection System Insufficient Flow	P2441	Secondary Air Injection System Switching Valve Stuck Closed
P0492	Secondary Air Injection System Insufficient Flow	P2442	Secondary Air Injection System Switching Valve Stuck Open
P2257	Secondary Air Injection System Control "A" Circuit Low	P2443	Secondary Air Injection System Switching Valve Stuck Closed
P2258	Secondary Air Injection System Control "A" Circuit High	P2444	Secondary Air Injection System Pump Stuck On
P2259	Secondary Air Injection System Control "B" Circuit Low	P2445	Secondary Air Injection System Pump Stuck Off
P2260	Secondary Air Injection System Control "B" Circuit High	P2446	Secondary Air Injection System Pump Stuck On
P2430	Secondary Air Injection System Air Flow/Pressure Sensor Circuit	P2447	Secondary Air Injection System Pump Stuck Off